MODELING MOBILITY ENGINEERING IN A THEATER LEVEL COMBAT MODEL

THESIS

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Brian K. Hobson

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ABSTRACT

This thesis describes the development of a methodology to model theater-level mobility engineering assets in the Joint Staff's Joint Warfare Analysis Experimental Prototype (JWAEP) and to quantify the joint and Army doctrine that guides the task organization of engineers for combat and which quantifies engineer mobility effects in combat. The methodology incorporates theater-level mobility engineering assets into the JWAEP by using Mission, Enemy,Troops available, Terrain, and Time (METT-T) principles which reflect joint and Army doctrine, and combines them with the existing basic concepts in other theater-level models. Additional aspects of the problem include determining the manmade and natural obstacles' delay and attrition effects, determining the obstacle intelligence acquisition procedures, identifying solution techniques, verifying the results, and making recommendations.

The proposed solution techniques provide a feasible methodology for maximizing the utility of organizing mobility engineers for combat based on a perception of existing obstacles and potential obstacle delay and attrition effects. The algorithms incorporate the engineer estimate process for organizing engineers for combat and employing appropriate doctrinal tactical breaching techniques. Consequently, the methodology not only provides accurate input to the JWAEP for approximating real world results, but it also provides a structured and quantifiable framework for joint and Army doctrine when task organizing and employing mobility engineers for combat.

MODELING MOBILITY ENGINEERING IN A THEATER-LEVEL COMBAT MODEL

I. INTRODUCTION

1.1 Purpose and Background.

The Army's doctrine capstone manual, FM 100-5, depicts engineers as a critical combat multiplier on the battlefield: "Engineers turn terrain into an asset for our forces and a weapon against the enemy. They provide the terrain-oriented battlefield operating system which, when closely integrated with maneuver and fire, wrenches the initiative from the enemy in order to defeat him. The challenge to engineers is to multiply the effectiveness of friendly forces on an intensely lethal battlefield" [20:1]. US Army combat engineers[1] respond to this challenge by closely integrating and conducting their combat functions with the combined arms team throughout the theater of operations.

The purpose of this thesis is to develop the algorithms and investigate the decision logic required to portray mobility engineering in the Joint Warfare Analysis Experimental Prototype (JWAEP) at a level of resolution which is appropriate for a theater level combat model.

More specifically, the following problems will be addressed:

1) Investigate the doctrinal procedures for acquisition of enemy obstacles.
2) Develop an algorithm to incorporate the delay time associated with encountering an obstacle complex.
3) Develop an algorithm to incorporate the appropriate attrition factors when interacting with an obstacle complex.

---

[1] Combat engineers are the engineer units which are integrated with maneuver elements to perform mobility, countermobility, and survivability engineer missions.

4) Develop the logic and algorithms to incorporate and represent the effects of natural obstacles.
5) Develop updated "costs" for the Dykstra algorithm to incorporate the obstacle effects of delay and attrition.
6) Investigate the decision logic required to model the employment of mobility engineering assets for a specific course of action within JWAEP.

1.1.1 JWAEP Background. The Joint Stochastic Warfare Analysis Research (J-STOCHWAR) , formerly known as the Future Theater-Level Model (FTLM), is the research effort and evaluation aid designed to identify a theater-level analysis capability that explicitly deals with uncertainty and variability in an aggregated theater-level representation of joint forces [43:1]. The JWAEP (Version 1.2) is the software simulation prototype which implements the research concepts of J-STOCHWAR.

1.1.2 JWAEP Purpose. The JWAEP is an interactive, two-sided, aggregated theater-level combat model based on an arc-node representation of ground, air, and littoral[2] combat [45:1]. The JWAEP simulates the uncertainty and variability in theater-level operational decisions and command and control procedures via random variables and stochastic processes with relatively low resolution. As a simulation, it is used in two modes: interactive wargaming and closed-form stochastic analysis.

In the interactive wargaming mode, decision makers use the JWAEP model as a tool to predict the outcomes and impacts of their decisions in a theater-level campaign. The JWAEP model is capable of analyzing measures of effectiveness (MOEs) at critical events, such as the commitment of the reserve force, and analyzing the outcomes of major

---

[2] Littoral representations in JWAEP are pending implementation and documentation.

sequences of events, such as a Corps deliberate attack. With these modeling capabilities, decision makers can determine the effects of their decisions as they relate to force composition, force projection, force employment, operational and tactical outcomes, doctrinal adherence, and perceptions of the enemy. The JWAEP model, in this mode, is extremely interactive and powerful because its "foundation" is centered on the command, control, communications, and intelligence (C^3I) process, whereby the human-in-the-loop (HITL) decision maker receives perceptions of the enemy. Thus, the uncertainty in the C^3I process is depicted through perceptions upon which a decision maker must base operational and tactical decisions -- a realistic, stochastic representation of "the fog of war".

Operating in the closed-form stochastic analysis mode, analysts can answer questions concerning force structure, effects of major equipment and systems acquisition, campaign planning, and joint interoperability doctrine.

1.1.3 Engineer Organization.

> **"On a march in the vicinity of an enemy, a detachment of the Companies of Sappers and Miners shall be stationed at the head of the column, directly after the Van Guard for the purpose of opening and mending the roads and removing obstructions."**
>
> *from George Washington's General Orders, 3 August 1779*

Throughout our nation's history, leaders have understood the importance of organizing engineers to enhance the maneuver force. Engineers perform their vital combat role throughout the theater of operations, from the forward line of troops (FLOT) back through the communication zone (COMMZ) and to the ports of entry. Although the

engineer orientation is always forward, the engineer force structure must be tailored to meet and accomplish the various missions throughout the theater. Consequently, the engineer architecture forms the various engineer units into an organization that is flexible and responsive to commanders at all echelons in the theater [16:12]. Table 1-1 reflects the engineer organizational command and control structures for various force deployment levels at different theater sizes and complexities.

Table 1-1 Comparing Theater Support Engineer Command and Control Elements

SIZE OF FORCE	**SIZE/COMPLEXITY OF THEATER ENGINEER MISSION**			
	Large/Mature	Large/Immature	Small/Mature	Small/Immature
Multicorps	ENCOM	ENCOM	ENCOM	ENCOM
Single Corps	ENCOM / TA Bde	TA Bde	TA Bde	TA Bde
Division	CORPS Bde / GROUP	GROUP	GROUP	GROUP
Brigade	GROUP	GROUP	GROUP	GROUP

Additionally, each engineer command and control headquarters is normally allocated three to seven subordinate engineer units. These subordinate engineer units are of various structures and sizes and can range from small specialized detachments to combat engineer battalions in support of a maneuver force. Appendix A lists the various engineer organizations, their basis for allocation, and their mission statements. Due to the variations in types of engineer units, their organization for combat is solely dependent upon the potential engineer requirements and missions in theater. A typical engineer organization for a maneuver corps' engineer assets is depicted in Figure 1-1. Additionally, each maneuver infantry division (ID) in the corps, depending upon the type, will have its

organic divisional engineer support. Figure 1-1 depicts two different types of maneuver divisions: heavy and light with their different organic engineer organizations [35:34].

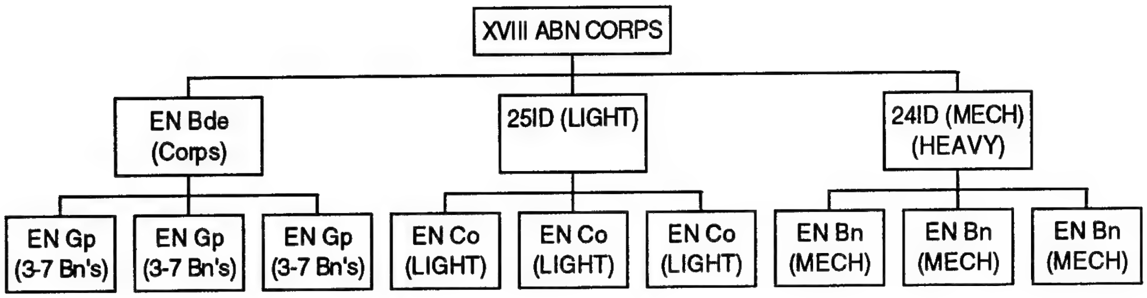


Figure 1-1 Engineer Organization for Maneuver Corps

Figure 1-2 reflects a possible organizational chart for theater level engineer assets. Each engineer brigade (EN BDE) and each engineer group (EN GP) may contain three to seven subordinate engineer units.

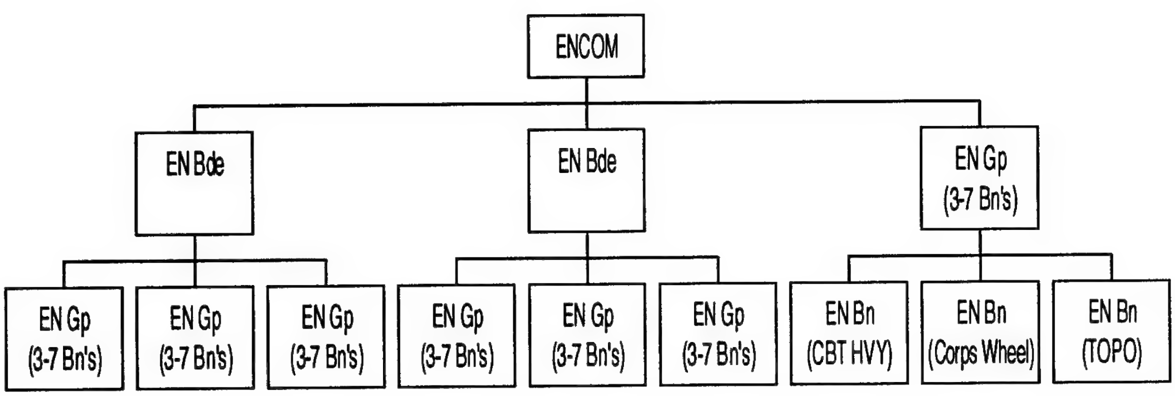


Figure 1-2 Theater-Level Engineer Organization

1.2 Research Scope.

To develop the decision logic required to portray mobility engineering effects in JWAEP, the research depicted in Chapter 2 encompassed the following areas: JWAEP model composition, Army engineer doctrine, and other combat models.

The JWAEP model composition is the first research area. In developing the algorithms and decision logic to support mobility engineering representation within JWAEP, it is necessary to comprehend and summarize the architectural aspects and qualities of the JWAEP model.

Army engineer doctrine research includes the doctrinal principles of obstacle intelligence acquisition procedures and the tactical considerations for the employment of combat engineers. Obstacle acquisition is primarily terrain analysis. It is the engineers' responsibility to provide the maneuver commander with an analysis of the terrain which focuses on trafficability and identifies likely enemy obstacle locations [16:44]. A thorough assessment of the terrain is critical to exploit potential weaknesses in the enemy's defense. Reconnaissance is vital to verify the accuracy of the engineers perception and assessment of natural, cultural, and reinforcing obstacles. Engineers identify specific reconnaissance requirements and augment dismounted patrols and scouts to identify obstacle characteristics [16:44]. The tactical considerations for the employment of engineers is the next research area (Army doctrine). For a decision maker utilizing JWAEP to witness the impacts of the decisions, the model must represent real combat as closely as possible [10:5]. Since combat engineers greatly influence the battlefield, a combat model's representation of the mobility engineering functional area is crucial to the validity of the

decisions to be drawn from the model [38:5]. Hence, the representation of engineers and engineer effects must be integrated with existing Army doctrine to realistically portray engineers on the JWAEP battlefield. The representation of the engineer tactics and engineer mobility effects include mobility tactics and delay and attrition algorithms for maneuver elements when a manmade or natural obstacle is encountered.

Analysis of other combat models can provide insight for modeling engineer assets in JWAEP. The existing algorithms and decision logic in these models provide potential insight for representation of mobility engineering assets and their effects in the JWAEP model. Although each model contains conceptual differences as to the level or extent of modeling engineer units and their effects, these models provide a structured foundation from which the engineer mobility logic can be developed. Furthermore, these models provide a representation of the necessary resolution level required to explicitly model the effects of engineer units in JWAEP.

1.3 Problem Statement Definition.

Representing the different engineer mobility effects and the engineer organization for combat in a model is a complex task [38: 26-27]. All of the characteristics and major factors influencing the engineer organization and employment, all of the factors influencing the acquisition of obstacle information, and all of the factors influencing the effects of mobility engineering tasks affect the decision logic to model mobility engineer units in JWAEP. These factors, along with the factors of METT-T (Mission, enemy, troops available, terrain, and time), are the uncertainties which must be analyzed to adequately model mobility engineering in JWAEP. Hence, the overall problem definition can be

stated as follows: *implicitly model engineer mobility representation and explicitly model obstacle acquisition capabilities and engineer mobility effects in JWAEP that accommodate Army doctrine.*

1.4 Overview and Format.

The following chapters contain the research, the proposed methodology, the results and analysis, and the recommendations and conclusions.

Chapter 2 contains information on the JWAEP model composition, Army engineer doctrine on obstacle intelligence acquisition and the tactical mobility considerations for engineer employment, the mobility effects of engineer units, and other combat models. Chapter 3 contains the proposed methodology to implicitly model mobility engineering units and explicitly model obstacle acquisition procedures and mobility engineering effects. Chapter 4 discusses and demonstrates the results, analysis, verification and validation of the methodology. Chapter 5 provides recommendations and conclusions.

II. DISCUSSION OF LITERATURE

2.1 JWAEP Composition.

Models of combat activities can be classified or categorized in several different ways. However, Hartman and a Military Operations Research Society (MORS) workshop committee on Simulation Taxonomy (SIMTAX)concluded that a model's composition can be classified by construction (the design of the model) and by its qualities (the real entities and processes which the model represents) [1:2; 30:1-5 - 1-12].

2.1.1 JWAEP Construction. In this MORS workshop, the attendees developed a taxonomy for warfare to address the relational dimensions of a combat model. One of these dimensions of a model is construction. The workshop summarized four categories in the construction dimension of models: human participation, time processing, treatment of randomness, and sidedness [1:9-11].

Human participation is the extent to which a human presence is allowed or required to influence the operation of the model [1:9]. The JWAEP level of human participation varies depending on its mode of operation and the purpose of the simulation. In the closed form mode, the JWAEP operates at the low end of the spectrum for human participation. In this mode, an analyst inputs the external data parameters and the JWAEP becomes noninteractive until the simulation is complete. Analysts use this "noninteractive" mode to analyze force structures, major weapon systems acquisition, campaign planning, and joint interoperability doctrine.

In the wargaming mode, however, human participation can become quite extensive. Based on the simulation objectives, human interaction with JWAEP varies.

For example, if the simulation objective was to determine the most feasible course of action for a Corps deliberate attack, then the decision maker would interact extensively with JWAEP to obtain information, develop perceptions, conduct assessments, and make decisions at various phases of the attack.

Time processing is the mechanism or implicit methodology within a model for how the model treats changes to entities or processes over time [1:9-10]. Within the JWAEP model, time is continuously processed and is categorized as "dynamic". In other words, the JWAEP model explicitly considers time dependent processes. The simulation time clock operates in a faster mode than real time and the ratio of simulation time to real time is dependent upon the user.

The treatment of randomness is the explicit consideration of random events or the representation of various outcomes for the same event [1:10]. The JWAEP is a very distinct model with respect to randomness. Currently, the JWAEP is the only theater-level model which explicitly handles uncertainty and randomness. Most theater-level models are deterministically based with some stochastic processes. JWAEP, however, is the only theater-level model which is stochastically based. The modeling imperatives, which provide the foundation for the JWAEP model's stochastic nature, include: (1) combat is stochastic, (2) many input values are unknown and unknowable, and (3) operational issues have more effect on outcomes than tactical issues at the theater-level of planning and execution. This representation of the stochastic nature of uncertainty is critical as scenarios grow increasingly uncertain, environments become unknown, and conflicts become more nonlinear in nature.

Sidedness refers to the number of collections or alliances of resources working in or through the model toward a common goal [1:11]. The JWAEP is a two-sided asymmetric, dual reactive model, in the sense that the JWAEP model is sufficiently flexible to allow either side to use a particular set of weapons systems or tactics. Also, each side is permitted to react to the opposition's actions based on a perception of the opposition and the environment.

2.1.2 JWAEP Qualities. A model is a simplified representation of the entity it imitates or simulates [1:1; 30:1-2]. From an operations research perspective, the goodness of a model is judged according to how well it achieves its purpose and how well it accurately portrays the phenomena being modeled. From a military perspective, desirable traits of a model include transparency, predictiveness, realism, relevance, and simplicity. Additionally, each model has certain qualities of specific entities and processes that the model attempts to represent. Hartman and the MORS workshop identify and categorize model qualities accordingly: domain, span, environment, force composition, scope of conflict, mission type, and level of detail [1:7-8; 30:6-7].

Domain is the physical or abstract space in which entities execute their processes [1:7]. In its current version, the JWAEP model supports the land and air dimensions with the full scale sea dimension forthcoming.

Span is the scale of the domain: global, theater, regional, local, and individual [1:7]. The span in the JWAEP model is to contain any theater of operation in which an existing terrain database encompasses the area of operation. The current span

accommodates a Korean prototype database, with future enhancements and modifications supporting additional databases.

Environment is the texture of the domain [1:7]. It determines the conditions within which the postulated campaign will occur. The environment's characteristics include the terrain (elevation, mobility restrictions/degradation, and surface type), the atmosphere (climate, winds, season, day/night distinction, and obscurants), and the electronic environment (electronic warfare and Nuclear, Biological, and Chemical). JWAEP encompasses the environment using an arc-node system. Units moving along the arc-node network experience the characteristics of the environment at each arc and node.

In the JWAEP model, movements occur on two distinctive arc-node networks: the ground and air domain dimensions.[3] Each network consists of two types of nodes: physical and connector nodes. Physical nodes correspond to actual areas on the ground and water and typically represent cities, zones, or areas which might be key to the scenario. Connector nodes are logical constructs instead of physical areas, used to link arcs together. These nodes do not have any associated terrain and are used as a mechanism to make terrain networks more realistic and account for non-homogeneity (nonlinear avenues of approach and different terrain types along a route). Connector nodes are internal to the model design and are not visually displayed on the network.

---

[3] The sea arc-node network is pending release of the littoral representations. Current representation can be developed by defining carriers as airbases on water-nodes and Marine amphibious units as ground units that move over water nodes.

The air network contains an air grid system which is overlaid onto the theater of operations. It is analogous to and usually dependent upon the ground network. The size of the squares in the air network vary according to the scenario [34: 29].

The arc system links the physical nodes. Each arc retains the attributes of the corresponding terrain between the physical nodes. If the terrain type changes, then a connector node is introduced so that different arcs can account for the terrain's non-homogeneity. Each arc contains distinct attributes: distance between nodes, road classification, width of the mobility corridor, side capable of using, and terrain classification [34: 25].

The JWAEP model portrays various types of terrain. These include flat, rough, mountain, urban, DMZ, water (naval), and water (amphibious). Each of these types of terrain impact the movement between and actions on the nodes. The JWAEP model does not presently represent the effects of weather except in the air mission planning algorithm. Day and night conditions are simulated in the JWAEP model.

Force Composition is the portrayal of the mix of forces (combined forces, joint forces, service component) [1:7]. The JWAEP model represents joint (Army, Navy, Air Force, and Marines) and combined (allied) forces. It compensates for the asymmetric composition of each force and permits the user to define as many types of units as desired. Generally, a maneuver brigade is the nominal unit size for each side.

Scope of Conflict is the category of weapons [1:7]. The JWAEP model currently only allows the asymmetric use of conventional weapons. However, future

enhancements to the JWAEP model will incorporate the effects of nuclear, biological and chemical weapons.

Mission Area is the recognized combination of weapons and procedures used to accomplish a specific objective [1:7]. JWAEP explicitly depicts any mission area based on the input parameters (weapons systems and units). Specifically, it focuses on the command, control, communication and intelligence (C^3I) operational performance associated with the ground, air, and "limited" littoral representations of combat.

Level of Detail of Processes and Entities is the lowest discrete entity modeled and the resolution of the interactive actions which affect these entities [1:7-8]. The JWAEP models a maneuver brigade and its supporting units (battalions) as the lowest ground unit entities. The size of the maneuver brigade depends on the modeler's specified input parameters; however, most maneuver units are typically labeled as light or heavy and can range from approximately 1,000 to 2,500 soldiers. A ship and an aircraft are the lowest littoral and air entities represented in JWAEP.

At the heart of the JWAEP model is the command, control, communications and intelligence (C^3I) process. It is the central focus of the JWAEP model and is decomposed into five functions: planning, detection, fusion, decision, and control. The JWAEP model, to the extent possible, attempts to make decisions internal to the model based on a clearly defined set of rules. These rules, however, are easily modified by the analyst, preserving a decision maker's flexibility. Another critical process which is embodied in JWAEP is the element of maneuver (ground and air). The scheme of maneuver is based on perceptions of enemy operations and locations generated by the C^3I process in the model. With these

perceptions, decision makers will formulate plans, determine courses of action, and implement specified tactics [6:4, 43:22]. Several other processes are modeled in the JWAEP; however, due to its immature nature, some developing processes will be incorporated into the JWAEP model during future enhancements. These developing processes include direct fire support assets, countermobility and survivability engineer assets, and the air and littoral modules.

One underdeveloped process in the JWAEP model is an algorithm or methodology to model the effects of engineer units as an operational asset [44:1-3]. More specifically, the JWAEP model currently lacks the algorithmic logic to model theater-level mobility engineering assets. As a key combat multiplier, engineers play a vital role in the outcome of a battle.

2.1.3 JWAEP Architecture. Understanding the JWAEP architecture and its processes is critical prior to developing a methodology to accurately represent engineer forces and their effects. The most critical elements of the JWAEP architecture in relation to mobility engineering are the JWAEP representation of combat units, the unit's equipment, the unit's weapons, the unit's movement, and the portrayal of obstacles within JWAEP.

2.1.3.1 Combat Units. JWAEP represents combat units by utilizing a basic building block structure to portray the desired scenario. This representation is found in the unit class data file of JWAEP [42: 21; 45: 14]. The unit class data file provides the essential information to describe a particular unit type in JWAEP, e.g., armor brigade or mechanized division. The data specified in the file describe the unit's icon, Table of

Organization and Equipment (TO&E), movement parameters, and formation. Multiple instances of these units are possible in a scenario, where each unit instance has a predetermined degree of variance [42: 23]. For example, an armor brigade instance may initialize with only 95 percent personnel strength and 90 percent of its authorized tanks. Additionally, the specified unit size is used to determine the unit's formation size [45: 15]. Table 2-1 depicts an example of a unit type definition as portrayed in JWAEP.

Table 2-1 JWAEP Unit Type Definition

```
1002 "Armor Brigade in Armor Division"
SIDE . .CLASS . . FUNCTION . . MAX.SUPPORT.RANGE . . GROUP . AD.TYPE
 1       1001         1                      50                1001        0
   EQUIPMENT
         ID . . . . QTY . . . . .STD.DEV
         1110     116          10        (M1A1 Tank)
         1200     126          10        (M2 IFV)
         1210     12           2         (ITV)
         1230     16           4         (FISTV/GLLD)
         1275     54           9         (NonUS IFV-25MM)
         1500     12           1         (MLRS)
         1620     32           4         (120MM/4.2 Mortar)
         1800     888          100       (Blue Troops, personnel)
   END.EQUIPMENT
```

In the example in Table 2-1, the type unit is defined with the unit four-digit number 1002. The side, 1 or 2, depicts friendly or enemy. The unit class, 1001, is used in the sensor fusion model and maps a specific TO&E to a unit category obtained from the *class.dat* file. The function of the unit specifies maneuver unit, 1, or support unit, 2. The maximum support range is the maximum distance from its center of mass that a support unit will provide general support. The group indicates the generic unit category for the sensor fusion model. The AD type maps the organic air defense assets of the unit to the air defense system type found in the *adtype.dat* file. The equipment ID number identifies

the equipment type and links the unit's equipment with ATCAL [45:29]. All instances of a unit with the same unit class number have identical types of equipment; however, equipment quantities may differ by the numerical standard deviation (STD DEV) [42:23].

2.1.3.2 Ground Combat Equipment. The various types of ground equipment that a user can specify and include with each unit class type are defined in the JWAEP file *equipment.dat*. This file represents all of the different types of equipment and weapons that can potentially be represented in a specified scenario [42:21; 45:17]. Additionally, this file links JWAEP to the Attrition Calculation (ATCAL) data files so equipment attrition can properly be represented [45:17]. Currently, 123 different equipment types are available in JWAEP. Table 2-2 depicts the representation of an M1A1 tank equipment data file in JWAEP [42:21]. The JWAEP User's Guide discusses the acronym headings illustrated in Table 2-2 [42:21].

Table 2-2 JWAEP Equipment Type Definition

1100 "M1A1"

SIDE	CLASS	CATEGORY	TGT.TYPE	STONS	AD.SITE.TYPE	IMPORTANCE
1	1	1	10001	60.0	0	.80

PALLETS	SIZECAT	LAPE%LOSS	DROP%LOSS	PP.EQ.CAT
2	3	10	40	10001

WEAPONS:

ID	QTY
1101	1
1102	1

END.WEAPONS

As noted in Table 2-2, this file also specifies the four-digit weapon identification number for all weapons represented within JWAEP as part of a weapon platform.

2.1.3.3 Weapons. Weapon representation within JWAEP is accomplished through the equipment data file and the type of equipment data file. This specification is conducted for all weapon types, including soldiers for both sides (Red and Blue forces). JWAEP specifies and categorizes each weapon according to a four-digit identification number, the parent or weapon platform equipment name, the side, and the weight of a single round of ammunition [42:23; 45:25]. Table 2-3 illustrates an example of JWAEP's weapon representation.

Table 2-3 JWAEP Weapon Type Specification

ID	NAME	SIDE	LBS/ROUND
1101	M1A1	1	62.63
1102	M1A1	1	1.22
2101	"T72"	2	62.63

2.1.3.4 Ground Movement. Ground movement within JWAEP is conducted at two different rates--unopposed and opposed. These movement rates are defined for each terrain class, each formation, and each unit category, and these rates are used for movement over arcs and through nodes. The unopposed movement rates are user defined in the unit class data file. The opposed unit movement rates, however, are the attrition based rates developed from the opposed movement algorithm in the Concepts Evaluation Model (CEM). This algorithm in CEM determines the movement based on a curve which is a function of terrain type, posture, and relative attrition. Within JWAEP, the mobility data input file specifies these opposed movement rates [45:16-17]. The various JWAEP posture levels which can affect the opposed movement rates include:

1) BADD: Blue Attack, Red conducts Deliberate Defense.
2) BADH: Blue Attack, Red conducts Hasty Defense.
3) BADI: Blue Attack, Red conducts Intense Defense.
4) STATIC: Neither Side can Attack (uses unopposed movement rates).

5) RADI: Red Attack, Blue conducts Intense Defense.
6) RADH: Red Attacks, Blue conducts Hasty Defense.
7) RADD: Red Attacks, Blue conducts Deliberate Defense.

Additionally, ground movement occurs along a path (traversing an arc or a series of arcs). Two factors influence the movement of a unit: the path or route to follow and the rate at which the unit moves along the desired route. The orders given to a unit affect the unit's path selection process: automatic path generation process (Dykstra algorithm) or manual input path which specifies intermediate nodes. Using automatic path generation, the Dykstra algorithm determines the least cost path to the desired destination node where cost is a function of the time it takes a unit to traverse the path and the attrition which is estimated to be received along the traversed arc. Currently, JWAEP does not treat attrition as a cost but assigns an infinite cost if the traversing unit is planning an administrative or tactical march and perceives enemy contact. If the unit is planning a movement to contact or attack, then these orders will automatically force the Dykstra algorithm to select the path containing opposition, regardless of the cost [45:38].

2.1.3.5 Obstacle Representation. The representation of manmade obstacles within JWAEP is conducted through the use of obstacle complex classes of data structures. These data structures are very similar in architecture to the unit data type structures discussed previously [42:33-38]. Each obstacle complex class possesses user specified attributes, such as obstacle type, frontage, depth, and density. JWAEP depicts natural or cultural obstacles such as rivers; however, JWAEP does not currently model the effects of these obstacles.

2.1.3.6 JWAEP Ground Combat Attrition. Within JWAEP, close combat defines two opposing units which are engaged with each other and nonclose combat occurs between forces not in direct combat. JWAEP's ground combat attrition methodology currently encompasses only close combat and not nonclose combat. Without engineer representation, modeling of nonclose combat was not required in JWAEP because attrition of units did not occur unless close combat conditions existed. However, with obstacle representations in JWAEP, it is highly possible for units to encounter obstacles and receive delay and attrition effects while in a nonclose combat situation.

Close combat ground attrition calculations in JWAEP are represented and modeled using the Attrition Calibration (ATCAL) model developed at the United States Army Concepts Analysis Agency [45:41]. Close combat is triggered when entering an enemy occupied node or encountering an enemy while traversing an arc [45:39]. Adjudication of this close combat is accomplished through ATCAL. ATCAL is an aggregated attrition model consisting of numerous equations which compute attrition in an iterative process with input parameters provided by JWAEP. ATCAL calibrates the attrition in JWAEP using results from similar battles in the Combat Sample Generator (COSAGE) and adjudicates the close combat attrition at trigger events (battles) or every 12 hours. The ATCAL attrition adjudication process determines the expected strength and movement of the forces at the end of a cycle or trigger event [42:39; 45:33, 39, 41-42]. The ATCAL supporting comparison data is maintained in JWAEP in the *wpnvseq.dat* file [45:33].

2.2 Army Engineer Doctrine.

The Army engineer capstone manual, FM 5-100 *Engineer Combat Operations*, depicts the engineer aspects of doctrine. Additionally, the 5-xxx series of Army Field Manuals (FMs) illustrate the principles of engineer doctrine in terms of engineer organization and the five engineer functional missions on the battlefield.

2.2.1 Engineer Organizational Principles. Strategic objectives, the nature of the theater of operations, and the forces available all influence the design of the theater commander's campaign plan. The requirements for engineer forces and types of organizations evolve from this campaign plan and impact the engineer architecture. Eight engineer organizational principles, derived from FM 100-5, the Army's capstone doctrine manual, guide and stabilize the organization of engineer forces in the theater of operations. These principles apply to the development of engineer organization and architecture at all levels of command [16:14, 38:23]. The subsequent paragraphs identify and describe these organizational principles.

Task Organize Engineer Forces to Requirements. Theater mission requirements impact and drive the size and composition of engineers units. Frequently, a mix of engineer units is necessary to achieve a balance of requirements and units' capabilities [16:14].

Give Priority to the Main Effort. History has repeatedly shown that there are never enough engineers on the battlefield to execute all of the potential missions. Consequently, engineers must be concentrated with the main effort to ensure its success, and risk is accepted elsewhere [16:14].

Integrate Engineers with Maneuver and Fire. The scheme of maneuver drives the engineer plan. Engineers operate to integrate mobility and countermobility with fire and maneuver to form the triad of combat power. Fire and maneuver will not be effective without friendly freedom of maneuver [16:14].

Ensure Current Engineer Operations Promote Future Force Operations. Because engineer missions require an abundance of time to accomplish, it is imperative that the engineer forces begin executing missions early. Hence, engineer leaders must anticipate future operations and posture their force structure accordingly [16:14].

Do Not Hold Engineers in Reserve. Organic engineer forces who are detached from their parent maneuver unit and held in the rear area cannot provide critical engineer support as required. As a vital and limited asset on the battlefield, it is imperative to mission success that the allocation of engineer forces and their time be planned in detail to support the maneuver commander's intent [16:14].

Build a Logistically Sustainable Force. Resources are always limited. Engineer sustainment and the supporting logistics structure require planning. A shortfall in engineer materials would restrict the effects of the engineer force [16:14].

Maintain Effective Command and Control. An effective integration of the maneuver and engineer plans will use all available engineer headquarters, align them with maneuver boundaries, and hand off operations smoothly between the headquarters [16:14].

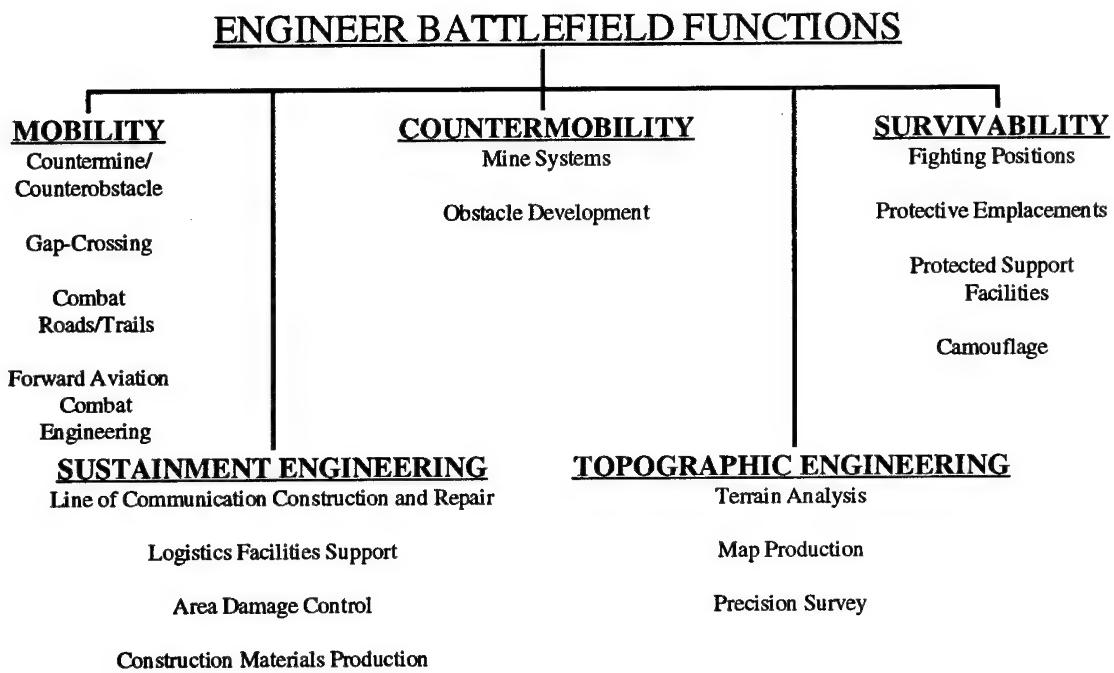
Use All Local Resources. Engineer resources (materials, equipment, and manpower) belonging to local governments, other services, and allied forces are present in theaters. Using these resources will augment available engineers, releasing more engineer units forward from the COMMZ to the combat zone [16:14-15].

2.2.2 Engineer Role and Functions on the Battlefield. The role of the engineer is to multiply the effectiveness of friendly forces on an intensely lethal battlefield by integrating engineer support, providing engineer expertise, and recommending engineer actions [16:26, 38:28]. Engineers conduct five primary engineer functions in the theater of operations to fulfill this role: mobility, countermobility, survivability, sustainment engineering, and topographic engineering.

Mobility enables the force commander to maintain his freedom of maneuver and position tactical units into positions of advantage over the enemy [38:28]. Additionally, mobility engineering reduces movement limitations imposed by the natural terrain or enemy actions. Countermobility directly attacks the enemy commander's ability to maneuver his forces where and when he desires. Engineer countermobility restricts enemy maneuver, increases the enemy's vulnerability to direct and indirect fire, and protects friendly forces from counterattack [38:28]. Survivability provides concealment and protective shelter from the effects of enemy weapons and enables friendly forces to fight from positions that would otherwise be untenable [38:28]. Sustainment Engineering is the engineer effort which provides depth in space and time in battle by ensuring that logistical sustainment operations to the force in theater can occur [38:28]. Topographic Engineering defines and delineates the terrain for force commanders so that effective

planning and timely operations can be conducted [38:28]. These five engineer functions ensure responsive and flexible support to the maneuver force on a dynamic battlefield. Some of the specific engineer missions for these five functions are depicted in Figure 2-1.

Figure 2-1 Engineer Battlefield Functions



2.2.3 Engineer Mobility Functions on the Battlefield. The engineer focus in offensive operations is on mobility; the ability to free the theater-level force to maneuver at will. The focus assists the maneuver commander to achieve and maintain concentration, speed, momentum, and flexibility [16:43]. Engineer terrain analysis and reconnaissance identifies the best routes for movement, and engineers assigned to the maneuver elements provide rapid breaching of obstacles. These obstacles may be natural (e.g., rivers), cultural (e.g., embankments), or reinforcing (e.g., enemy obstacle complexes) [38:19]. The actual types of engineer mobility functional tasks aligned with these obstacles include countermine and counterobstacle tasks, gap crossing tasks, construction and upgrade of

combat roads and trails, and the construction of forward aviation combat engineering [19:1-10].

During the conduct of engineer mobility operations, engineers focus on the achievement of the following goals.

1) To sustain the momentum necessary to retain initiative [19:1-10].
2) To overcome obstacles in stride through standardized execution [19:1-11].
3) To allow a force to move rapidly, mass, disperse and resupply [19:1-10].
4) To provide avenues of approach unexpected by the enemy because of difficult terrain [16:46].
5) To provide early detection of obstacles to movement [19:2-10].

While planning mobility tasks, the following principles assist in the engineer plan.

1) Bypass obstacles, if possible, and breach only if no alternative exists [19:4-7].
2) Prepare for overcoming obstacles and performing gap crossings as a part of the maneuver commander's plan [19:3-3].
3) Locate engineer mobility assets well forward in the leading maneuver units to assist with mobility tasks [16:43].
4) Locate countermine equipment (plows, rollers) organic to maneuver units with the lead elements [19:4-8].
5) Execute mobility tasks under the cover of darkness or smoke to reduce vulnerability [19:1-11].

2.2.4 Obstacle Intelligence Acquisition Procedures. Mobility engineering is a vital element of the Army's Battlefield Operating Systems (BOSs). Engineers have critical input into the maneuver commander's offensive plan so that capabilities are integrated into a single effort to defeat the enemy. Engineers integrate the engineer plan into the maneuver plan through the use of two processes: the engineer estimate and the Intelligence Preparation of the Battlefield (IPB) [16:23-24].

Using the engineer estimate, planners integrate mobility engineering into the maneuver plan based on METT-T, the commander's intent, and the commander's acceptable level of risk. Using the IPB process, engineer planners work closely with intelligence officers to provide the commander a perception of the enemy. As part of this process, engineers conduct analysis of the terrain. An engineer analyzes the terrain based upon observation, cover and concealment, obstacles, key terrain, and avenues of approach (OCOKA) and their impact on maneuver force operations [16:24]. Hence, the engineer analyzes the terrain and existing natural and cultural obstacles to "template" and estimate potential enemy obstacle locations. Following the estimate and IPB process, the engineer coordinates with the intelligence officer to develop the obstacle intelligence collection plan to verify the estimate. This collection plan involves satellite imagery, sensors, ground surveillance, engineer scouts, and patrols to deny or confirm the enemy obstacle locations in the engineer estimate. Upon validation of the estimate, the planners transform the engineer estimate into executable orders within the maneuver plan based on METT-T, the commander's intent, and the commander's acceptable level of risk. The commander uses the information from the obstacle intelligence collection assets to perceive the enemy's posture and obstacle threat and subsequently makes a decision as to whether to bypass, breach or bull-through the obstacle.

2.2.5 Tactical Considerations for the Employment of Engineers. Commanders visualize their battle space to set the relationship of friendly forces to one another, and to the enemy in time, space, resources, and purpose. In visualizing this battlespace, commanders and staffs conduct estimates to determine how best to accomplish their

mission. As they make these estimates, they explicitly consider the factors of METT-T, which have tactical, operational and strategic applications [20:6-13, 8-1]. However, each committed maneuver brigade normally needs the equivalent of an engineer battalion. Corps or theater engineer assets provide additional engineer forces, if needed. This allocation is based on METT-T, as is the subsequent employment of the allocated engineer forces 16:19]. Thus, the METT-T factors drive the organization and employment of mobility engineering assets. The relationship between the METT-T factors and decisions affecting the tactical employment of mobility engineers is depicted below.

M (MISSION): Posture of maneuver element (hasty attack, deliberate attack, etc.) and the required mobility engineer tasks associated with the posture.

E (ENEMY): The size, composition and posture of the enemy forces to include enemy engineer composition, availability of barrier material, and availability of engineer demolition.

T (TROOPS): Friendly mobility engineer assets available at each echelon and the status (% attrited, % committed) of these engineer forces.

T (TERRAIN): Analysis of associated terrain to include fields of observation, cover and concealment, potential and existing locations for natural, cultural and reinforcing obstacles, key terrain to include potential chokepoints on friendly maneuver, and potential avenues of approach for friendly maneuver and enemy counterattack axes.

T(TIME): The time available to accomplish the potential mobility tasks.

Therefore, the tactical considerations for the employment of engineers involve identifying the METT-T factors and the various uncertainties associated with these factors, and then task organizing engineers and assigning engineer mobility missions based on perceptions of the METT-T factors.

2.3 Combat Models

Several combat models offer examples of decision logic and algorithms that model mobility engineering. Although each model is conceptually different, these models provide insight for modeling the mobility engineering effects in JWAEP. The following sections contain an overview of various models and their "engineer characteristics". The models examined include the Vector-In-Commander/Engineer Functional Area Model (VIC-EFAM), the Tactical Warfare Model (TACWAR), and the Joint Theater Level Simulation Model (JTLS).

2.3.1 Vector-In-Commander/Engineer Functional Area Models (VIC-EFAM).

VIC is a two-sided deterministic simulation of combat in a combined arms (infantry, armor, aviation, artillery, engineer, etc.) environment designed specifically to study doctrinal concepts and tactics for sustained combat operations in a variety of scenarios. VIC represents the major elements of land and air forces at the US Army corps level with a commensurate enemy force in a mid-intensity conflict [40: 7, 5: 4].

The EFAM portion of VIC is the engineer alignment and model improvement effort initiated to upgrade engineer representation in existing Army models. The Engineer Studies Center selected VIC as the base model to implement this model improvement effort to increase the realism of VIC's portrayal of the combat engineer function [37:1-2, 40: 7-8].

The VIC-EFAM model is an extremely mature model compared to other models in reference to the combat engineer representation. Although a deterministic model, VIC-

EFAM's representation of engineers as a member of the combined-arms team produced the following improvements to engineer modeling [40:8]:

1) A more complete representation of the types of tasks engineers perform.
2) A new representation of engineer units, resources, and processes to allow a more accurate assessment of engineer capabilities.
3) A more detailed representation of the terrain features altered by engineers and an improved representation of maneuver unit interactions with these terrain features.

The VIC-EFAM model also incorporates the effects of engineer activities in terms of mobility tasks. VIC-EFAM portrays the ability of a ground unit to recognize the presence of the physical features of the terrain altered by engineers (obstacles) and the reactions to it (mobility engineering). Furthermore, VIC-EFAM represents the effects of terrain alterations and mobility reactions in terms of maneuver unit delay and attrition caused by encountering obstacles. These obstacle encounters include natural obstacles such as rivers and gaps. In this manner, VIC-EFAM explicitly models doctrinal mobility engineering effects through the use of distinct algorithms for delay, attrition, and future effectiveness [5:10-11]. However, these algorithms have limitations. These algorithms, due to the deterministic nature of VIC, employ extensive averaging and relative effect (look-up table) values [5: 48-57]. These algorithms may provide good approximations for a deterministic model. However, they do not represent the variability of engineer effects.

2.3.2 Tactical Warfare Model (TACWAR). TACWAR is a theater-level model designed to be an operational support tool with dual purposes of research and evaluation (facilitates the analysis of changes to a particular course of action) and force structure analysis [3:10]. TACWAR includes force mix capabilities at an aggregated level.

TACWAR is basically a deterministic, time-stepped model which allows some user interface. The command and control structure has some aspects of an automated decision model. However, most of the command and control inputs are predetermined by the scenario and the user's objectives. TACWAR's treatment of obstacles (natural and reinforcing) is deterministic and based on obstacle size. The only obstacle effect represented is the obstacle's impediment of movement. TACWAR is a viable and accepted operational model; however, its major flaw is the tremendous reliance on accurate analyst data input [3:39-43].

2.3.3 Joint Theater Level Simulation Model (JTLS). JTLS is a human-in-the-loop (HITL) theater-level model which drives wargames and exercises. JTLS serves as both an operations support and a force capability tool to assess combat between different force mixes or resources. It is primarily used for analysis, development, and evaluation of theater operational plans with dynamic interactions of intelligence, air, logistics, naval, and ground forces [12:1-1]. JTLS is a deterministic model which uses Lanchester-based methods to simulate combat. Deterministic Lanchester methods involve the use of mixed, heterogeneous, time-stepped differential equations to represent the dynamics of different forms of warfare. These equations are simple representations of combat, and do not consider tactics, C3I, and uncertainty. However, JTLS does account for the attrition and delay effects of obstacles and the clearance of obstacles. These attrition determinations and movement time delays are based on the size of the obstacle and the capabilities of the "clearing unit" [12:2-2].

2.3.4 Model Summary. All of the models discussed here treat randomness via deterministic methods and use deterministic attrition algorithms. JWAEP also uses a deterministic attrition methodology through the use of Attrition Calculation (ATCAL). Table 2-4 summarizes the important characteristics of all of the models.

Table 2-4 A Comparison of Mobility Engineering Modeling Techniques

	VIC-EFAM	TACWAR	JTLS
Allocation	• All assets placed into single file access file. • Allocated based on player selection.	• All assets placed into single access file. • Allocated based on player selection.	• All assets placed into single access file. • Allocated based on player selection.
Command & Control	• Doctrinal Assignment at all Levels	• Semi-Automated • User Input	• Interactive • Rule Based
Attrition	• Expected Outcome • Weighted Averaging	• Expected Outcome • ATCAL	• Lanchester based equations
Sidedness	• Two-Sided • Symmetric	• Two-Sided • Reactive • Asymmetric	• Multi-Sided • Reactive • Asymmetric
Treatment of Randomness	• Deterministic	• Deterministic	• Deterministic
Obstacles	• Natural/Reinforcing • Explicitly Models Effects • Affects Attrition • Impede Movement	• Natural/Reinforcing • Impede Movement	• Natural/Minefields • Impede Movement • Affect Attrition

2.4 Summary of Literature

Current Army engineer doctrine, information drawn from other combat models, and the existing JWAEP architecture can be used to model mobility engineering in JWAEP. The other combat models, however, offer limited benefits since most are

deterministic in nature and fail to model the uncertainty inherent in combat engineer operations. The VIC-EFAM model does provide an excellent foundation, however, for the explicit modeling of mobility engineer effects. Specifically, the VIC-EFAM algorithms for obstacle time delay and some attrition effects can serve as a foundation for the development of JWAEP algorithms for obstacle delay and attrition.

III. METHODOLOGY

3.1 Modeling Combat Engineer Units.

As discussed in previous chapters, engineer units conduct a variety of missions over the full battlefield spectrum with a variety of forces. Appendix A lists all possible engineer forces and the missions which these units conduct on the battlefield. Attempting to model all of these engineer units and the variety of missions they conduct is neither practical nor feasible in a low resolution model. The modeling efforts in this thesis focus on engineer forces which are organic to a maneuver division and selected engineer forces at the corps level which provide significant mobility assets, e.g., a corps engineer ribbon bridge company which provides tactical river crossing and rafting assets [42:25]. The modeling efforts were limited to this scope because a division is the primary maneuver element on the battlefield [20:6-13--6-14].

3.1.1 Divisional Engineer Units. The types of engineer units organic to a maneuver division vary according to the type of division (armored, mechanized, light, airborne and air assault) which each engineer unit supports. Table 3-1 reflects the various divisions and their supporting engineer forces.

Table 3-1 Divisional Engineer Force Types

TYPE OF DIVISION	ENGINEER UNIT SIZE	ENGINEER UNIT TYPE
Armored Division	Brigade	Mechanized
Mechanized Division	Brigade	Mechanized
Light Division	Battalion	Light
Infantry Division	Battalion	Wheeled
Air Assault Division	Battalion	Air Assault
Airborne Division	Battalion	Airborne

As depicted in Table 3-1, the armored and mechanized divisions (heavy divisions) each have a supporting mechanized engineer brigade which contains three engineer battalions. Each of these engineer battalions typically supports one of the division's three maneuver brigades with a vast majority of their engineer assets dedicated to mobility and survivability missions.

Each of the other types of divisions receive engineer support from a supporting organic engineer battalion. This supporting battalion is extremely limited in equipment assets and in general, a habitual support relationship between the divisional maneuver brigades and the supporting engineer companies is not present due to the equipment requirements and priorities of the main effort maneuver brigade in these other divisions. Engineer support in these divisions is typically allocated to the main effort maneuver brigade based on maneuver mission requirements. The engineer forces in a heavy division provide extensive support when compared to the capabilities of the organic engineer forces in the other divisions. Therefore, it is more illuminating and practical to model the engineer forces organic to a heavy division in this research effort since these forces provide the most significant amount of engineer support [42:26].

3.1.2 Corps Level Engineer Units. At the Corps level, an assigned engineer brigade is responsible for command and control of all engineer forces in the corps assigned area of operations. As specified in Appendix A, a corps level engineer brigade is a large, flexible organization containing a variety of engineer units which are specialized to support corps operations. Unlike the organic division engineer brigade, the corps level engineer brigade is task organized with engineer specialized units tailored to support the corps'

operations. Its subordinate engineer units might include three to five engineer groups and a number of engineer battalions and specialized teams. The corps level engineer brigade primarily focuses its efforts on providing additional support to the maneuver divisions' operations. For example, it provides all river crossing assets for a large scale deliberate river crossing operation and it augments organic division engineer assets for major offensive breaching operations. Table 3-2 illustrates the primary potential engineer units which would be task organized with a corps level engineer brigade and each of these unit's primary Table of Organization and Equipment (TO&E) engineer support mission.

Table 3-2 Corps Level Engineer Units and Primary Engineer Mission

ENGINEER UNIT	PRIMARY MISSION
Mechanized Engineer Battalion	Mobility
Combat Engineer Battalion, Wheeled	Countermobility
Combat Engineer Battalion, Light	Mobility
Combat Engineer Battalion, Airborne	Mobility
Combat Engineer Battalion, Heavy	Sustainment Engineering
Topographic Engineer Battalion	Topographic Engineering
Engineer Combat Support Equipment Company	Sustainment Engineering
Engineer Medium Girder Bridge Company	Mobility
Engineer Ribbon Bridge Company	Mobility

3.1.3 Engineer Units Modeled in JWAEP. Since JWAEP is a theater-level model, it is reasonable to assume that multiple corps and divisions should be represented as part of a mature theater scenario. Additionally, since the JWAEP scenario span is a theater in Korea, it is also reasonable to assume that a majority of the forces will be heavy (mechanized or armor) units like the present forces stationed in the Republic of Korea. Hence, the engineer units represented in JWAEP for a mature theater-level scenario in Korea should be those engineer forces which support heavy divisions and those corps level engineer forces which provide substantial support for mobility missions. Table 3-3 depicts

the engineer units which will be used in the JWAEP engineer module to model mobility engineering support.

Table 3-3 Engineer Units Modeled in JWAEP

ENGINEER UNIT	LEVEL OF SUPPORT	BASIS OF ALLOCATION
Engineer Brigade	Division	1 per Heavy Division
Mechanized Engineer Battalion	Corps	As needed
Combat Engineer Battalion (Light)	Corps	As needed
Combat Engineer Battalion (Airborne)	Corps	As needed
Medium Girder Bridge Company	Corps	4 per Corps
Ribbon Bridge Company	Corps	4 per Corps

3.2 Engineer Structures in JWAEP.

Due to the JWAEP architecture and construction specified in Chapter 2, engineer units, equipment, weapons, and instances should be represented within JWAEP's architectural parameters. Engineer units and their combat assets can be defined within JWAEP using the same architecture as defined for a maneuver unit [45:15-17].

3.2.1 Engineer Units. Unlike maneuver units which are represented in JWAEP down to the battalion level, the bridging units used to overcome natural obstacles within JWAEP must be defined at the company level (Ribbon Bridge Company, Medium Girder Bridge Company). However, the attribute qualities previously defined in JWAEP for a battalion level unit can be used. Since these bridging units possess large amounts of equipment, the bridging companies should be reflected with a unit instance icon of "111" depicting a battalion. This instance icon will ensure that the formation size for a bridging company occupies an equivalent maneuver battalion's formation size and space.

For all other engineer mobility support, the engineer battalion is the lowest level organization to be represented within JWAEP. However, each engineer battalion unit

possesses different attribute quantities. For example, the three engineer battalions in the engineer brigade supporting a heavy division are quite different from a corps level mechanized engineer battalion, a light combat engineer battalion, and an airborne combat engineer battalion. Table 3-4 illustrates an example of an engineer unit type definition for a divisional engineer battalion in a heavy division.

Table 3-4 Engineer Unit Type Definition

```
1080 "Div Engr Bn in Armor or Mech Bde"
SIDE . . CLASS . . FUNCTION . . MAX SUPPORT RANGE . . . GROUP . . AD TYPE
 1       1002       2                30                   1008        0
    EQUIPMENT
        ID . . . QTY . . . . . . STD DEV
        1240   29          5          (M113)
        1800   433         50         (Blue Troops, personnel)
        1900   6           1          (CEV)
        1901   12          2          (AVLB)
        1902   12          2          (M58A3 MICLIC)
        1903   6           1          (VOLCANO, 5-ton truck mtd)
        1904   21          4          (M9 ACE)
        1905   6           1          (M128 GEMSS)

    END EQUIPMENT
```

The engineer type definition depicted in Table 3-4 is a general illustration of an engineer unit. Table 2-1 and its explanatory remarks on page 16 of this document discuss the headings of this table. Appendix C, Engineer Structures, depicts the six possible mobility engineer units with their equipment (identification and quantity), capabilities, and weapons.

3.2.2 Engineer Equipment. JWAEP represents engineer equipment using the *equipment.dat* file. This architecture permits the representation of all engineer assets organic to an engineer unit for all combat engineer functional missions [42:30]. However,

for model clarity purposes, the engineer equipment should all be contained in a subdirectory file labeled *engr.equipment.dat.* Unlike maneuver equipment, engineer equipment normally does not possess an attrition inflicting weapon. Instead, engineer mobility equipment possesses a capability normally depicted in the form of a rate which describes the rate in which a piece of engineer equipment performs a particular engineer functional area mission. For example, one M58A3 mine clearing line charge (MICLIC) has a setup and employment time of 4 minutes for 100 meters in length of breach lane [17:2-4]. Hence, the MICLIC capability rate is expressed as 25 meters per minute or 1500 meters per hour. Table 3-5 portrays some examples of engineer equipment and their capability rates for mobility missions.

Table 3-5 Engineer Equipment Type Definition

ID....	NAME..............	SIDE....	BREACH RATE (METERS . HR)	GAP WIDTH SPAN METERS
1900	CEV	1	5000	0
1901	AVLB	1	0	17
1902	MICLIC	1	1500	0
1904	ACE	1	200	0
1930	RIBBON BRIDGE	1	0	215
1931	MGB	1	0	47

3.2.3 Engineer Weapons. Only limited pieces of engineer equipment possess weapons (CEV, M113 Armored Personnel Carrier). These weapons can simply be added to the existing architecture file in JWAEP *equipment.dat* file. However, it is important to note the difference between a weapon on a piece of engineer equipment (a 50 caliber machine gun on a Combat Engineer Vehicle: CEV) and a piece of equipment which utilizes demolition or rounds to reduce obstacles (a CEV's 165mm turret mounted

demolition gun which destroys log crib obstacles or other obstacles in the path of movement). Hence, the CEV has a weapon capable of attritting forces (50 cal), and one capable of reducing obstacles (165 mm gun). Engineer equipment which does not possess a "force-killing" weapon is represented in the *engr. equipment.dat* file where capabilities are expressed in terms of a rate (task per unit time). Engineer equipment possessing a "force-killing" weapon are depicted in the weapons file: *equipment.dat.*

3.2.4 Engineer Unit Instance and Orders. Engineer unit instances will adhere to the current JWAEP instance architecture found in the *units.dat* file. Each engineer ground unit will be defined according to its group (engineer battalion), type (divisional engineer battalion, ribbon bridge company, light combat engineer battalion, etc.), and the side type unit equivalent. The group identifies the generic engineer unit category which is used by the sensor fusion model to recognize generic unit types. The unit type uniquely identifies the TO&E data for a specific engineer unit. The side type unit equivalent defines enemy or friendly engineers and the equivalent base unit of measure. For example, a sensor receiving 450 engineer soldiers can fuse this data and determine which side these soldiers belong to and that this number roughly maps to a mechanized combat engineer battalion [42:31, 45:29].

Since combat engineer units are depicted as combat support type units [20:2-2, 2-24], engineer units can use the existing JWAEP orders structure for support type units [45:12]. These orders will generally include direct support and general support missions for combat units. However, units which are organic, attached or in operational control (OPCON), require three potential mobility missions to be added to the JWAEP support

unit order stream: BYPASS, BREACH, and BULL THROUGH. If a unit encounters an obstacle in JWAEP and the model is in closed form operation mode, the default setting for obstacle mobility tactic orders is BYPASS. This default setting is based on doctrinal employment of mobility tactics discussed in section 3.6.2 of this document. A JWAEP modeler can create an engineer unit through the unit instance architecture, initialize the engineer unit by providing orders for support to a maneuver unit. Using this method, JWAEP modelers can create a realistic and robust scenario where engineer units provide realistic mobility support throughout different phases of a theater-level campaign [42:31].

3.3 Methodology Assumptions.

The methodology portion of this thesis uses the following assumptions in developing solution techniques for modeling obstacle intelligence acquisition and obstacle delay and attrition effects in JWAEP.

1) The JWAEP theater is mature and divisions and corps are present.

2) Heavy divisions (armored and mechanized) are typical and representative of the divisions found in Korea.

3) All close combat actions will utilize the ATCAL model of adjudication; therefore, this thesis effort will only focus on nonclose combat actions.

4) Obstacles which are employed on arcs will be designated as "units" so that the obstacles can possess separate attributes and opposition maneuver units can perceive these separate attributes.

5) A maneuver unit's personnel and equipment are uniformly distributed throughout its formation, so the density of a unit is the number of soldiers or pieces of equipment per area (square meter) occupied.

6) A unit formation is approximated by a rectangle whose length and width varies according to the size, type and posture of that unit.

7) Contact with a mine produces attrition at the rate of one loss per mine.

8) The attrition and delay effects from an obstacle complex are the sum of the independent attrition and delay calculations caused by each obstacle within the complex.

9) Natural obstacle effect algorithms assume 100 percent reliability of the bridge and zero percent attrition of engineer bridging assets.

3.4 Methodology Overview.

The solution techniques for modeling engineer mobility effects in JWAEP incorporate the aforementioned assumptions and are presented these in a sequential order based upon the order which the modeled systems would appear in combat:

1) Obtaining intelligence acquisition on obstacles.

2) Calculating the delay and attrition effects of manmade and natural obstacles.

3) Linking these effects as a cost to the Dykstra algorithm which is used for route selection in the JWAEP model.

4) Determining a suitable mobility tactic for overcoming obstacles based on perceived delay and attrition effects.

3.5 Modeling Obstacle Intelligence Acquisition Procedures in JWAEP.

Obtaining information concerning the enemy's obstacle types, sizes, and locations is of vital importance in planning for and integrating the mobility plan into the maneuver commander's plan. Engineers commonly use a variety of intelligence acquisition assets to develop the engineer intelligence preparation of the battlefield so that a viable and supportable mobility plan can be developed [16:24]. Within JWAEP, intelligence on enemy units is collected via human reporting and sensors. The current modeling architecture of intelligence collection focuses on enemy units, and this same architecture can be used for obstacle intelligence acquisition since obstacles are depicted as "enemy unit icons" within JWAEP.

3.5.1 Existing JWAEP Intelligence Acquisition and Perception. Current intelligence acquisition, fusion, and perception of information is accomplished in JWAEP using different types of sensors and information communication between units using spot reports and situation reports.

Intelligence on existing enemy units is acquired using combat sensors, network sensors, and scheduled sensors. Combat sensors are allocated to both sides and represent the ability of one engaged unit to detect another. Combat sensors issue spot reports to model a unit reporting contact with the enemy [45:64-65]. Network sensors are also allocated to both sides and represent the intelligence collection capability of the using force along the user-defined subset of arcs and nodes. Network sensors report all enemy units which are currently on the sensor's arc or at the sensor's node at user-input random intervals. Scheduled sensors represent an area type surveillance or reconnaissance

mission which simulates an airborne or space information acquisition system. The scheduled sensor has an area footprint defined by width and length and it reports all enemy units within its footprint.

Sensor fusion is accomplished in JWAEP through sensor inputs and Bayesian updating [24:1, 27:1-2, 45:65]. Inputs from sensor observation on equipment and personnel are fused into probability vectors using Bayesian updating on the equipment and personnel observed versus the equipment and personnel in the most similar TO&E. This comparison and Bayesian updating is what produces the probability vector for the perceived size and type of unit.

3.5.2 Integration of Obstacle Intelligence Acquisition. Since manmade obstacles and obstacle complexes are represented as units within JWAEP [42:33], it is logical that obstacle intelligence acquisition procedures within JWAEP follow the same architectural framework as the enemy unit acquisition procedures. Hence, the same sensors and sensor fusion processes currently used in JWAEP for enemy units can be used for manmade enemy obstacles. However, a few modifications are necessary. The current fusion and Bayesian updating process is based on sensor inputs of enemy equipment. Enemy obstacle acquisition will be updated using the Bayesian process and the following algorithm:

1. Sensors provide input reports on obstacles where reporting includes the following fields:
    a. Type of obstacle: point, linear or area.
    b. Frontage length of obstacle.
    c. Depth of obstacle.
    d. Mine type and total number.
    e. Minefield density (per linear meter).
    f. Dry or wet gap.
    g. Depth of gap.
    h. Location of obstacle (center of mass and vertices) [42:36].
2. All sensor inputs on obstacles are received and fused.

3. Fused sensor inputs for fields of obstacles are compared to the fields of the most similar obstacle prototypes.
4. A probability vector is created via the Bayesian process for all obstacles. These vectors depict the probability or perception that an obstacle exists, its size and location, and the type of obstacle.

Like the enemy acquisition process, all three types of JWAEP sensors will be used to acquire enemy obstacle intelligence. Combat sensors will be used to represent the ability of a unit to report its contact with an obstacle. Network sensors and scheduled sensors, however, need to be placed or scheduled according to METT-T and the commander's intent. The user must specify locations of the sensors according to the mission, the type of terrain, the existence and location of natural obstacles, and known or perceived enemy locations. Since all of these factors influence the enemy commander's decision as to the locations of obstacle placement, it is imperative to locate limited sensor assets at locations which allow confirmation of suspected enemy obstacles.

In this manner, the obstacle intelligence process can use the current JWAEP sensor and fusion model with only minor modifications to the sensor field specifications and the user providing obstacle prototype information [42:33-34].

Obstacle intelligence requirements for natural obstacles are not as extensive as manmade obstacles since a majority of the necessary information on natural obstacles is available from the JWAEP terrain data base file. Attributes of these natural obstacles, such as gap width, depth and current velocity are also contained in the JWAEP terrain data base file.

3.6 Modeling Mobility Engineer Effects in JWAEP.

Modeling the effects of mobility engineer missions is accomplished in JWAEP by first understanding the mobility tactics employed to overcome obstacles and then by properly modeling the effects of these tactics with measurable effect representations. The VIC-EFAM model builders learned several valuable lessons concerning the representation of mobility effects and concluded that modeling the effects of engineer tasks are more important than modeling the task itself. It is not feasible for a model to measure requirements on engineer effort with any accuracy at all in the absence of a commensurate representation of the engineer effects [38:31]. Hence, the engineer mobility efforts are the various mobility tactics, and the measurable effects of these tactics are the time delay and attrition of the force due to overcoming an obstacle.

3.6.1 Mobility Tactics. Mobility tactics are the specific engineer tactical maneuvers or operations employed on the battlefield to overcome natural and manmade obstacles. Perhaps the single most difficult combat task a maneuver force can encounter is to maintain momentum and project combat power to the far side of an obstacle [15:2-1]. These engineer tactical maneuvers are commonly referred to as *breaching operations*. Army doctrine currently defines and specifies five types of breaching operations: bypass, in-stride breach, deliberate breach, assault breach, and covert breach [15:2-1, 2-8, 2-10].

The bypass operation is a breaching operation which avoids the obstacle [15:2-1]. Based on intelligence acquisition, the mission, and the commander's intent, a maneuver commander may decide to employ a bypass of the obstacle and change the direction of movement of his force to avoid the obstacle. The bypass is the most preferred

mobility tactic and is the first option chosen if the encountering unit is not engaged and the commander is attempting to preserve the force [16:44, 46]. Consequently, the effects of this mobility tactic are the attrition caused by the initial discovery of the obstacle and the delay time associated with maneuvering around the obstacle.

The in-stride breaching operation is a rapid technique using actions on contact to overcome unexpected or lightly defended obstacles [15:2-8, 3-1]. This breaching operation takes advantage of surprise and initiative to overcome an obstacle with minimal loss of momentum. This operation is used against weak defenders or simple obstacles and is executed from the march or movement formation upon contact with the obstacle. The in-stride breach is the most common breaching tactic employed since it usually maintains the momentum of the maneuver force [15:3-2]. The effects of this breaching operation are attrition and delay associated with breaching through the obstacle.

The deliberate breaching operation is very similar to the in-stride breaching operation with a few exceptions. The deliberate breach is typically characterized by thorough reconnaissance, detailed planning, extensive preparation, and explicit rehearsal, and is commonly used against strongly defended obstacles and extensive obstacle complexes [15:2-8, 4-1]. The deliberate breaching operation normally requires extensive amounts of preparation time and a massing of forces to overcome the strongly defended objective. The effects of this breaching operation are similar to the in-stride breaching operation; however, the delay time is extensively more due to the required preparation time and attrition is normally significantly higher due to the strong enemy defenses of the obstacle.

The assault breaching operation is usually only employed with dismounted forces upon the obstacles which are placed to defend an objective -- *final protective obstacles*. This operation enables a force to penetrate an enemy's final protective obstacles onto the objective and destroy the defender in detail. The assault breach is normally conducted with smaller engineer teams and it provides a maneuver force with the mobility it needs to gain a foothold into the enemy defense and exploit success by continuing the assault through the objective [15:2-8, 5-1]. The effects of this breaching operation are normally higher levels of attrition due to the high intensity defenses of the final protective obstacles and the delay time associated with breaching through the obstacles.

The covert breaching operation is a special breaching operation used during periods of limited visibility to secretly pass through obstacles. Covert breaching centers around using stealth and surprise to reduce the obstacle and minimize casualties. Similar to the assault breach, the covert breach is normally employed on an enemy's final protective obstacles; however, instead of employing overwhelming masses of combat power to maintain momentum, the commander sacrifices time for casualty reduction and employs surprise as the principle element of maneuver [15:2-10, 6-1]. The effects of this breaching operation, if successful, are higher delay times and minimal attrition.

Although not designated as a specific type of breaching operation, *bulling-through* is also a course of action which the maneuver commander can employ. The bull-through technique is a desperate decision made when a maneuver commander must react immediately to extricate his force from an untenable position within an obstacle and no

other breaching operations are seemingly possible [15:2-1]. When a force has encountered and is already within an obstacle and the commander has absolutely no time to employ engineer assets, or his unit is starting to receive fires and taking heavy losses, then the commander may employ the bull-through technique and force his unit through the obstacle rather than waiting for engineer support or withdrawing. Normally, the effects of this technique are high levels of attrition and a reduced amount of delay time.

A maneuver commander has at his disposal five types of breaching operations and the bull-through technique. However, not all of these operations are germane to this thesis, which seeks to model mobility engineer effects within a nonclose combat environment in JWAEP. The assault and covert breaching operations are higher resolution close combat actions not readily adaptable or appropriate for the low resolution representation in JWAEP. These two operations can best be modeled and represented in high resolution COSAGE runs which are used as a baseline in the ATCAL attrition adjudication process which already exists in JWAEP. The deliberate breaching operation is also a high resolution action which is associated with anticipated intense close combat situations.

The bull-through, the bypass, and the in-stride breaching operation are the three actions which will explicitly be modeled in JWAEP using separate delay and attrition effects algorithms instead of using ATCAL. These three actions are the most representative and appropriate for explicit representation within JWAEP considering its low level of resolution and the assumption of nonclose combat conditions.

According to current engineer doctrine, units which are currently not engaged (nonclose combat) will seek to bypass known obstacles when possible [16:44, 46]. Units which are currently engaged in battle (close combat), however, and time is a critical factor, will generally employ a breaching tactic as opposed to bypassing the obstacle. As a last resort, the unit may attempt a bull-through technique.

3.6.2 Modeling Doctrinal Mobility Tactics. As previously discussed, two mobility tactics (in-stride breach and bypass) and a mobility technique (bull-through) are the most appropriate operations to model in JWAEP due to resolution compatibility and the ability of JWAEP to use ATCAL for close combat conditions. Therefore, a decision maker using JWAEP would have at his disposal, the three operations listed above upon encountering an obstacle.

Assuming that nonclose combat conditions exist, a maneuver commander would overcome this obstacle using existing Army engineer doctrine [5:44]. This supporting engineer doctrine for mobility tactic usage enhances the maneuver plan, preserves the force, and maintains the momentum and flexibility of the maneuver force. Since the maneuver force is presently not engaged in combat, the mobility tactics in order of employment priority are bypass, in-stride breach, and bull-through as a last desperation effort [5:44, 46].

Bypass is the most preferred mobility tactic [5:44, 46] because of the flexibility and preservation of force which it maintains. Maneuver commanders seek to identify obstacle locations early in the intelligence preparation of the battlefield (IPB) process so that lateral routes can quickly be identified and momentum can be maintained.

The in-stride breach is the next preferred mobility tactic because it preserves momentum by quickly passing the maneuver force through the obstacles. This mobility tactic is often employed in a hasty attack when speed is critical and the maneuver commander cannot make time to conduct explicit planning and rehearsals.

The bull-through technique is only employed as a last resort when the maneuver unit has severe time limitations or when the unit is in an obstacle and begins to receive fires. The bull-through is extremely time efficient; however, this technique tends to yield significantly more losses.

Under nonclose combat conditions, the maneuver commander should always seek to employ a bypass mobility tactic when encountering an obstacle. If the obstacle cannot be bypassed (a river), then the maneuver commander should employ an in-stride breach tactic to quickly overcome the obstacle and push combat power to the far side of an obstacle.

<u>3.6.3 Influencing Factors on the Employment of Mobility Tactics.</u> Several factors influence the type of tactic and ability of a maneuver commander to employ a particular mobility tactic. These factors include:

(1) Engineer Assets Available
(2) Type of Obstacle Encountered
(3) Size of Obstacle Encountered
(4) Opposition of Defense Level Intensity of Obstacle
(5) Perceived Delay Upon Encountering Obstacle
(6) Perceived Attrition Upon Encountering Obstacle
(7) Maneuver Posture of Unit
(8) Size of Unit Encountering Obstacle
(9) Mission of Unit Encountering Obstacle
(10) Terrain Surrounding Obstacle
(11) Perceived Proximity of Enemy to the Obstacle

Since numerous uncertainties encompass the mobility tactic decision process, doctrine was introduced to simplify the process during certain conditions of battle. Consequently, during conditions of nonclose combat, doctrine states that a bypass technique is used to alleviate unnecessary uncertainties of breaching the obstacle [5:44, 46, 47].

3.6.4 Obstacle Class Representation. The different types of obstacles which can potentially be employed are too numerous to model. However, a majority of these different obstacles can be classified into one of three different classes of obstacle types: point, linear, and area. Since obstacles classified into one of these three classes possess similar characteristics and attributes, this generalization of obstacle types will simplify delay and attrition calculations over a given obstacle complex. For example, minefields are typically area type obstacles; tank ditches, berms and wire are generally linear type obstacles, and log cribs, partially demolished bridges, and barriers are typically point type obstacles. Consequently, the delay and attrition calculations will use data categorized by obstacle class and these calculations will be summed over the entire obstacle complex.

3.6.5 Mobility Engineer Effects on Movement (Delay). An obstacle delay effect on a maneuver unit is a function of the obstacle class (point, linear, and area) and type, the size of the obstacle (frontage and depth) relative to the size of the encountering unit, and the mobility tactic (breach, bypass and bull-through) employed by the encountering unit [5:47-52]. Hence, using nonclose combat conditions and the current Army engineer doctrine previously discussed, most of the delay calculations will result from the bypass tactic; however, algorithms for all three tactics are provided..

The VIC-EFAM documentation provides explicit realistic algorithms for delay calculations for all three mobility tactics. These algorithms have already been verified and validated as part of the engineer model improvement program (EMIP) [5:1-3, 47-52]. Hence, these algorithms will serve as a foundation for the delay algorithms in JWAEP. Additionally, an explanation of these algorithms requires the following variable definitions:

- TD: the total delay assessed to a unit in an obstacle complex where the number of obstacles goes from $j = 1, \ldots, n$.
- DD_j: the discovery delay for a unit locating an undiscovered obstacle j in an obstacle complex ($j = 1, \ldots, n$ obstacles).
- BD_j: bypass delay time for encountering unit to bypass obstacle j.
- BT_j: breach time for conducting an in-stride breach or bull-through technique for obstacle j.
- TP_j: time penalty due to crossing obstacle j.
- OD_j: depth (kilometers) of obstacle j.
- OF_j: frontage width (kilometers) of obstacle j.
- FBD_j: fraction of speed used for breach/reconnaissance delay for obstacle j.
- FCD_j: fraction of speed used for maneuver unit crossing delay for obstacle j.
- S: unopposed speed of unit.
- OSR_j: obstacle strength reduction factor for obstacle j.
- R: radius of encountering unit (from center of unit mass to outer most element)(kilometers).

The modified VIC-EFAM algorithm for computing total delay in JWAEP [5:49] is defined:

$$TD = \sum_{j=1}^{n} (DD_j + BD_j + BT_j + TP_j) \qquad (1)$$

This algorithm sums over n obstacles in the obstacle complex to yield a total delay time, TD, for the entire obstacle complex.

Discovery delay (DD_j) times for the three different obstacle classes are denoted in Table 3-6. These discovery delay times are fixed times expressed in hours and

are dependent upon the class of the obstacle and the mobility tactic employed for newly discovered obstacles only. These times reflect a 15 minute command and control delay and an execution delay which is obstacle class dependent for bringing engineer assets forward to breach a particular obstacle class or for conducting reconnaissance for a bypass route [5:51].

Table 3-6 Discovery Delay (DD) Times (Hours) for Obstacle Classes

		Mobility Tactic Employed		
Obstacle Class i	Obstacle Class Type	Bypass	Breach	Bull-Through
1	Point	.25	.5	.25
2	Linear	1	.5	.25
3	Area	2	.75	.25

The bypass delay time for obstacle j in the obstacle complex, BD_j, only applies if the encountering unit employs a bypass tactic. The bypass delay time is expressed in hours and it is the time for the encountering unit to maneuver around the obstacle. The bypass delay time is depicted in the following algorithm [5:48-50].

$$BD_j = (OD_j + OF_j/2)/(FBD_j * S) \qquad (2)$$

The fraction of speed used for breach and reconnaissance delay (FBD_j) for obstacle j in equation (2) is a fixed value which is dependent upon the obstacle class and mobility tactic [5:49-50]. Table 3-7 depicts these values for the three classes of obstacles. Table 3-7 also illustrates the FBD_j for each mobility tactic since FBD_j will be used in subsequent equations.

Table 3-7 Fraction of Speed for Breach and Reconnaissance Delay (FBD_j)

Obstacle Class i	Obstacle Class Type	FBD_j (Bypass)	FBD_j (Bull/Breach)
1	Point	.80	.13
2	Linear	.50	.08
3	Area	.30	.05

The breach time for conducting an in-stride breach or bull-through technique for obstacle j, BT_j, only applies if the encountering unit employs a breaching or bull-through technique on a newly discovered obstacle. The breach time algorithm is depicted in Equation (3) [5:48-49].

$$BT_j = OD_j / (FBD_j * S) \tag{3}$$

The fraction of speed for obstacle j, FBD_j, is depicted in Table 3-7.

The time penalty for obstacle j, TP_j, is only applicable for obstacles which were not bypassed. The TP_j is the time required for the maneuver unit to cross obstacle j once it has been breached or bulled-through. The time penalty is depicted in Equation (4) [5:48-49].

$$TP_j = [((2 * R) + OD_j) * (1 - OSR)] * [(1/(S * FCD)) - (1/S)] \tag{4}$$

The variables depicted in equation (4) were previously defined on page 52. Obstacle strength reduction, OSR, is subsequently discussed in section 3.7.3 of this document and OSR values are depicted in Table 3-10 on page 75. The fraction of speed used for maneuver unit crossing delay (FCD) is a fixed value which is dependent upon the obstacle class. Table 3-8 depicts these values for the three classes of obstacles [5:49-50].

Table 3-8 Fraction of Speed for Maneuver Unit Crossing Delay (FCD)

Obstacle Class I	Obstacle Class Type	FCD
1	Point	.99
2	Linear	.75
3	Area	.56

The point obstacle has a FCD value equal to .99 because once the point obstacle is breached, it is ineffective and virtually nonexistent. This ineffectiveness of a breached

point obstacle is also reflected in the obstacle strength reduction (OSR) value depicted in Table 3-10.

Since JWAEP obstacles are represented using instances of obstacle complexes [42:33-36], the delay time for an instance of an obstacle complex is the sum of the individual obstacle delays within the obstacle complex (Equation (1)). This equation permits both a perceived delay and an actual delay once adjudication of the obstacle complex is performed. A perceived delay exists based on sensor fusion inputs of obstacle existence and the perceived attributes (type, size, location) of these obstacles. Upon encountering an obstacle and employing a mobility tactic, adjudication of the obstacle with the maneuver unit can occur. The perception and adjudication of delay are discussed in sections 3.7.2 and 3.7.3 of this document.

Additionally, equation (1) can be modified to reflect the obstacle complex delay effects during periods of limited visibility or night time conditions. During these conditions, the value obtained for TD in equation (1) is multiplied by 1.5 to yield an obstacle complex total delay time for obscured visibility conditions. The value of 1.5 is a standard value used in engineer planning considerations to represent the effects of obscured visibility [17:17-1].

An example of the delay that results when a unit encounters a minefield is provided to illustrate the application of equations (1 - 4). The enemy has employed 1200 antitank mines for a minefield whose dimensions are perceived to be 100 meters in width and 300 meters in depth and whose density is 1.5 mines per linear meter. A heavy mechanized battalion is conducting movement along the arc containing the undiscovered

minefield at an unopposed speed of 15 kilometers per hour and the unit desires to bypass the obstacle. The current strength of the battalion is 750 soldiers and its formation area is 200 meters wide and 700 meters in length with a radius equal to 364 meters. Therefore, using this known or perceived information from JWAEP, the total delay, TD, for the encountering unit can be computed using the delay equations (1 - 4). The given information:

UFW = 200 meters.
UD = 700 meters.
OF = 100 meters.
OD = 300 meters.
S = 15 kilometers/hour.
R = 364 meters.
OSR = 0 (undiscovered obstacle).

Using equation (2) to determine the bypass delay,

$$BD = (OD + OF/2)/(FBD * S)$$
$$BD = [300 + (100/2)] / (.30 * 15000)$$
$$BD = 350 \text{ meters} / 4500 \text{ meters per hour}$$
$$BD = .08 \text{ hours}$$

Using Table 3-6 to determine the discovery delay (DD) time,

$$DD = 2 \text{ hours}$$

Using equation (1) to determine the total obstacle delay time (TD),

$$TD = (DD_1 + BD_1 + BT_1 + TP_1)$$
$$TD = (2 \text{ hours} + .08 \text{ hours} + 0 + 0)$$
$$TD = 2.08 \text{ hours}$$

The maneuver battalion perceives it will incur an obstacle delay of 2.08 hours if it encounters the obstacle and employs a bypass mobility tactic.

3.6.6 Mobility Engineer Effects on Attrition Calculations. An obstacle attrition effect on a maneuver unit is a function of the obstacle class (point, linear, and area) and

type, the size of the obstacle (frontage and depth) relative to the size of the encountering unit, and the mobility tactic (breach, bypass and bull-through) employed by the encountering unit [5:39-41; 42:46-49]. Like the delay calculations, the attrition calculations are based on nonclose combat and current Army engineer doctrine. A minefield is the only attrition producing obstacle, so all of the attrition will result from initial discovery losses from minefields, which are area obstacles. Assuming nonclose combat and a bypass tactic, no other attrition will be occur. If, however, a bypass tactic cannot be employed, then the obstacle must be breached or bulled-through and losses will occur as a result of the breaching or bull-through operation and as a result of crossing the maneuver force through the obstacle.

Attrition, unlike the delay effects, produces different effects for different types of units. Upon discovering an obstacle, the encountering unit will receive discovery losses to the front of the unit (the covering force) if the obstacle is a minefield. Upon discovery and encountering the obstacle and assuming nonclose combat conditions, the maneuver unit will attempt to bypass the obstacle to avoid additional attrition. If a bypass is untenable, then the maneuver unit will employ an in-stride breach tactic and utilize existing engineer assets. Using an in-stride breach tactic, the assigned engineer forces will overcome the obstacle and receive losses as a result of breaching the minefield. These losses are dependent upon the density of the minefield, the depth of the minefield, and the engineer equipment utilized to conduct the breaching operation. After the engineers clear and proof lanes through the obstacle, the maneuver force will receive minimal crossing losses while negotiating the obstacle. If neither a bypass nor in-stride breach tactic can be

used, then the maneuver commander may decide to employ a bull-through technique as a last resort. Employment of a bull-through technique will produce crossing losses to the maneuver unit. These losses are dependent upon the density of the minefield, the depth of the minefield, and the width of the front of the encountering unit.

The following algorithm yields the total number of unit losses for an obstacle complex based on employing one of the three mobility tactics. These unit losses may be expressed in terms of personnel or a specific type of equipment. Let:

TL = the total losses assessed to a unit for negotiating an obstacle complex.
DL_j = the discovery loss for a unit locating an undiscovered obstacle j in an obstacle complex (j = 1, ..., n obstacles).
BL_j = the loss for an engineer unit breaching an undiscovered obstacle j in an obstacle complex.
CL_j = the losses for a maneuver unit crossing an undiscovered obstacle j in an obstacle complex after an engineer unit has breached the obstacle.
BTL_j = the losses for a maneuver unit using a bull-through technique on an undiscovered obstacle j in an obstacle complex.

Then, the total loss algorithm is:

$$TL = \sum_{j=1}^{n} (DL_j + BL_j + CL_j + BTL_j) \tag{5}$$

Equation (5) sums the total unit losses over n obstacles in the obstacle complex where losses are expressed in terms of personnel or a particular type of equipment.

Due to the nonclose combat conditions, however, a heavy maneuver unit encountering a minefield obstacle which cannot be bypassed would need only deploy a mine clearing line charge (MICLIC) to breach the obstacle. The MICLIC is a standoff piece of breaching equipment which enables the engineer force to breach a minefield without receiving attrition. Since fielded to the Army in 1988, the MICLIC has become

the standard breaching equipment for use due to its standoff capability which produces no attrition [21:19]. If the heavy maneuver unit cannot bypass the obstacle or breach it with a MICLIC, then it would use tank mounted rollers, plows, or rakes. These breaching systems were developed during Operation Desert Shield/Storm to breach minefields with loose soil conditions (sand) [21:11]. Since JWAEP's current span is Korea, the use of these breaching systems is not realistic due to the rocky, mountainous conditions. If, however, the JWAEP span is expanded to other regions where conditions permit the use of these breaching systems, then historical data indicate a loss rate of 2 systems per 61 used or 0.03 systems lost per usage [21:11]. Therefore, based on nonclose combat conditions in JWAEP and the doctrinal usage of breaching equipment, the breaching loss, BL, for an engineer unit in equation (5) is negligible.

Additionally, the obstacle crossing losses for a maneuver unit, CL, depicted in equation (5) is negligible as a result of the nonclose combat conditions present in JWAEP. Crossing losses for an obstacle are a result of the enemy covering fires placed on the maneuver unit in the obstacle. Crossing losses do not result from minefield effects since it is assumed that the engineers have properly breached, proofed, and marked lanes through the obstacle and that the maneuver force can properly conduct movement along the marked lanes. Under nonclose combat conditions, equation (5) can be simplified to the following equation:

$$TL = \sum_{j=1}^{n}(DL_j + BTL_j) \tag{6}$$

Using equation (6), the discovery losses, Dl_j for obstacle j, are computed with the following variable definitions:

UFW = a maneuver unit's formation frontage width (meters).
UD = a maneuver unit's formation depth (meters).
OF_j = the frontage width (meters) of obstacle j.
MFD_j = the minefield density of obstacle j. Expressed as number of mines per minefield linear meter. The standard minefield density employed is 1.0.
DOU_j = the density of a unit or the number of soldiers or pieces of equipment which occupy one square meter of space at obstacle j. Expressed as number of soldiers or pieces of equipment per square meter (equation 7).
CUS_j = the current unit strength (raw number) for personnel or equipment in the encountering unit at obstacle j.
$P(OBS\ EXIST)_j$ = the perception or probability that obstacle j exists prior to actually encountering obstacle j.
FLD_j = the front line depth of a unit (meters) at obstacle j

The density of a unit at obstacle j, DOU_j, is depicted:

$$DOU_j = CUS_j / (UD * UFW) \tag{7}$$

The front line depth, FLD_j, is the depth in meters of the encountering unit's front line or the distance between the first and second lines of the unit's formation at obstacle j. This parameter is included in the algorithm because combat conditions are generally nonlinear in nature [20:6-7, 6-12]. A unit's front line formation will not be linearly arranged across the battlefield. It will, however, occupy some nonlinear space in depth to distribute its front line forces across the battlefield (FLD_j). This depth parameter, FLD_j, is dependent upon the posture, mission, speed and formation of the unit, the terrain, the perception of enemy contact, and available unit assets. However, assuming nonclose combat conditions exist and a uniform distribution of a unit's equipment and personnel throughout its formation, then the FLD_j at obstacle j can be defined:

$$FLD_j = [1/DOU_j]^{.5} \tag{8}$$

Using different conditions or different types of maneuver forces (e.g. light infantry division), the FLD_j parameter will change.

Because the soldiers and equipment are uniformly distributed, the linear distance between soldiers and equipment across the front line will equal the linear distance between soldiers or equipment from the first line to the second line in depth (FLD_j). Assuming that each soldier or piece of equipment contacting a mine is lost, two different equations are used to compute discovery losses based on the conditions present. These conditions involve comparing a minefield's density, MFD_j, (number of mines per linear meter) to an encountering unit's density across its frontage (number of soldiers or pieces of equipment per linear meter of frontage). The MFD_j is a parameter available in the JWAEP database [42:33-34], and the density of a unit across its frontage is computed using the inverse of equation (8). The equations for discovery loss, DL_j, are depicted:

If $MFD_j \geq (1/FLD_j)$, then

$$DL_j = (1/FLD_j) * \text{Minimum}[UFW, OF_j] * [1 - P(OBS\ EXIST)_j] \tag{9}$$

If $MFD_j < (1/FLD_j)$, then

$$DL_j = MFD_j * \text{Minimum}[UFW, OF_j] * (\text{1 soldier or piece of equipment per mine}) * [1 - P(OBS\ EXIST)_j] \tag{10}$$

Equations (9) and (10) produce the losses to the maneuver unit (equipment or personnel) upon encountering a newly discovered obstacle. Equations (9) and (10) realistically assume that a maneuver force and its equipment are uniformly distributed throughout its formation and that the enemy effectively employs obstacles in standard densities with natural terrain so that either the full width of the unit front or the full width

of the obstacle front is encountered [42:44]. Additionally, equations (9) and (10) realistically assume that attrition occurs at each obstacle j prior to encountering the next obstacle, j+1, in the obstacle complex. Updating the CUS_j after each obstacle encounter satisfies this assumption. Furthermore, equations (9) and (10) account for obstacle intelligence acquisition and the perception or probability that an obstacle exists prior to encountering it. The more intelligence acquired on an obstacle's existence and its attributes, then the less likely the unit is to receive discovery losses from the obstacle.

The following example of the attrition results for discovery loss when a unit encounters a minefield illustrates the application of equations (9) and (10). The enemy has employed 1200 antitank mines for a minefield whose dimensions are perceived to be 100 meters in width and 300 meters in depth and whose density is 1.5 mines per linear meter. This minefield is denoted as obstacle 1. A heavy mechanized battalion is conducting movement along the arc containing the minefield and the unit's probability or perception of obstacle existence is 0.75. The current strength of the battalion is 150 pieces of equipment and 750 soldiers with a formation area of 200 meters wide and 700 meters in length. Therefore, using this known or perceived information from JWAEP, the discovery loss at obstacle 1, DL_1, for the encountering unit can be computed using equation (9) or (10). The given information:

UFW = 200 meters.
UD = 700 meters.
OF_1 = 100 meters.
OD_1 = 300 meters.
MFD_1 = 1.5 mines/linear meter.
CUS_1 = 750 soldiers or 150 pieces of equipment (5 soldiers/piece of equipment).

$P(OBS\ EXIST)_1 = 0.75$
$MINES_1 = 1200$

Using equation (7),

$DOU_1 = CUS_1/(UD * UFW)$
$DOU_1 = 150/(700 * 200)$
$DOU_1 = .00107$ pieces of equipment per square meter

Using equation (8),

$FLD_1 = [1/DOU_1]^{.5}$
$FLD_1 = [1/.00107]^{.5}$
$FLD_1 = 30.57$ meters between each piece of equipment

To determine which DL_1 equation to use, (9) or (10), MFD_1 is compared with a unit's density across its frontage ($1/FLD_1$):

$MFD_1 = 1.5$ mines/linear meter
$1/FLD_1 = .033$ pieces of equipment/linear meter
$MFD_1 > 1/FLD_1$, so equation (9) is used.

Using equation (9),

$DL_1 = (1/FLD_1) * \text{Minimum}\ [UFW, OF_1] * [1 - P(OBS\ EXIST)_1]$
$DL_1 =$ (.033 pieces of equipment/meter) * Minimum[200 meters, 100 meters] * (1 - 0.75)
$DL_1 = .83$ pieces of equipment lost

The maneuver battalion perceives it will lose .83 pieces of equipment as a result of initially discovering the minefield, DL_1. Since there are 5 soldiers per piece of equipment, the perceived personnel loss equals (5) * (.83) or 4.15 soldiers lost as a result of initially discovering the minefield, DL_1.

Using equations (9) and (10), the bull-through technique losses for obstacle j, BTL_j, are defined as follows. Let:

DL_j = discovery loss at obstacle j computed from equations (9) or (10).
UD = a maneuver unit's formation depth (meters).
OD_j = the obstacle depth (meters).
OF_j = the frontage width of obstacle j(meters).

$ROWS_j$ = the number of minefield rows for obstacle j.
$MINES_j$ = the total number of mines in obstacle j.

Using the perception from JWAEP for obstacle intelligence, the input parameters $MINES_j$, MFD_j, and OF_j [42:33-34] are obtained for each obstacle j and are used to calculate the number of rows in the minefield:

$$ROWS_j = MINES_j / (MFD_j * OF_j) \tag{11}$$

Using the discovery loss at obstacle j, DL_j, from equation (9) or (10), BTL_j is defined:

$$BTL_j=\{DL_j/[1\text{-}P(OBS\ EXIST)_j]\}*Minimum[(UD/FLD_j), ROWS_j] - DL_j \tag{12}$$

Equation (12) produces the losses to a maneuver unit (equipment or personnel) due to employing a bull-through technique and is based on the same assumptions and parameters used for equations (9) and (10).

Using the values from the previous example for discovery loss, the following example illustrates a practical application of equations (11) and (12) for determining the bull-through losses for a unit employing this tactic through a minefield. Using equation (11),

$$ROWS_1 = MINES_1/(MFD_1 * OF_1)$$
$$ROWS_1 = 1200/(1.5 * 100)$$
$$ROWS_1 = 8 \text{ rows of mines in obstacle 1.}$$

Using equation (12) and the discovery loss, DL_1, results from the previous example, the bull-through losses, BTL_1, are depicted:

$$BTL_1 = \{DL_1/[1\text{-}P(OBS\ EXIST)_1]\} * Minimum[(UD/FLD_1), ROWS_1]\text{-}DL_1$$
$$BTL_1 = \{.83/[1\text{-}.75]\} * Minimum\ [(700/30.57), 8] - .83$$
$$BTL_1 = (3.32 * 8)\text{-}.83$$
$$BTL_1 = 25.73 \text{ pieces of equipment lost}$$

The maneuver battalion will lose 25.73 pieces of equipment as a result of employing a bull-through technique through the minefield. Since there are 5 soldiers per piece of equipment, the perceived or expected personnel loss equals (5) * (25.73) or 128.65 soldiers lost as a result of employing a bull-through technique through obstacle 1, BTL_1.

Since JWAEP represents obstacles using instances of obstacle complexes [42:33-36], the attrition effects of the individual obstacles within the obstacle complex can be summed using equation (6) to obtain a total unit loss (personnel or equipment) for an instance of an obstacle complex.

Using the values from the previous two examples for calculating discovery losses, DL_1, and bull-through losses, BTL_1, the total equipment losses for the maneuver battalion using equation (6) is depicted for encountering obstacle 1:

$$TL = DL_1 + BTL_1$$
$$TL = (.83 + 25.73)$$
$$TL = 26.56 \text{ pieces of equipment lost}$$

The total losses for the maneuver unit encountering the obstacle and employing a bull-through tactic are 26.56 pieces of equipment lost or 132.8 soldiers lost.

Equation (6) also permits both a perceived attrition effect and an actual attrition effect. A perceived attrition effect exists based on sensor fusion inputs of obstacle existence and the perceived attributes (type, size, location) of these obstacles. These perceived attribute values allow calculation of a perception of attrition, and the probability of obstacle existence represents the uncertainty of discovery losses based on intelligence acquisition. When a unit encounters an obstacle and employs a mobility tactic,

JWAEP adjudicates the actual obstacle attrition effects. To determine the actual discovery losses for obstacle attrition effects using equations (9) and (10), the value used for P(OBS EXIST) is the last value prior to encountering the obstacle; this probability will not be 1.0. If the probability value is 1.0, then the obstacle is not undiscovered or perfect information and intelligence is known. The perception and adjudication of attrition are discussed in sections 3.7.2 and 3.7.3 of this document.

Additionally, dividing equation (6) by the total unit personnel strength or the total unit equipment strength prior to encountering the obstacle complex yields the fraction of the unit's personnel or equipment, a decimal scalar, lost due to encountering the obstacle complex. This scalar is the value used to compute the total arc cost for movement in Dykstra's modified algorithm in section 3.7.1 of this document.

3.6.7 Delay Effect from Rivers and Gaps. The current architecture of JWAEP permits the physical representation of rivers and large gaps; however, no mechanism exists to reflect the effects of these natural obstacles. Current JWAEP methodology assigns an infinite cost or time to arcs containing these natural obstacles so the Dykstra algorithm for route selection will not select an arc containing these natural obstacles.

Rivers and gaps are major impediments to maneuver freedom in the Korean scenario. JWAEP should model the effects of these natural obstacles on maneuver forces and their movement. The following methodology will more accurately represent the effects of these obstacles on the actions of the maneuver force.

Rivers and streams are considered nonfordable or nonswimmable if their depth exceeds 1.5 meters [17:7-2]. Current velocity also determines the fordability of the

obstacle; however, since current velocities are highly dependent on high resolution factors such as daily weather conditions and seasons of the year, it is not practical to consider the relevance of current velocity in a low resolution model. Each heavy division contains organic armored vehicle launched bridges (AVLBs) which are capable of breaching wet or dry gaps no more than 17 meters wide. Since these engineer assets are readily available to the maneuver force and require minimal time to employ and retrieve (2-5 minutes), gaps capable of being crossed with this asset should not be considered obstacles [17:7-3]. Therefore, the only natural obstacles designated as natural obstacles in a JWAEP scenario are those rivers and streams whose depth exceeds 1.5 meters and whose gap width exceeds 17 meters and those dry gaps whose gap span exceeds 17 meters.

To designate an obstacle as a natural obstacle in JWAEP, the area which it occupies along or across an arc should be designated with a connector node at each end so that a separate arc is created just for this obstacle. In placing a connector node at each end of the natural obstacle's effect area, the JWAEP user can then assign a different mobility factor to the arc between the connector nodes which will impede, but not prevent, the movement of forces through this node. These reduced mobility factors are a function of the type of gap (wet or dry) and the span of the gap.

As previously depicted in Table 3-3 (page 36), a mature theater such as Korea will have approximately four engineer ribbon bridge companies (for wet gaps) and four engineer medium girder bridge companies (for dry gaps). Based on the type of gap, one of these two engineer units will be employed to overcome the obstacle. Each of these units possesses different bridging times for the type of gap to be bridged. As summarized

in Appendix C (Engineer Structures), each bridging unit possesses the bridge gap capability (in meters) and bridge erection times (in hours) depicted in Table 3-9 [17:7-7, 7-32, 7-40].

Table 3-9 Engineer Bridge Unit Capabilities

Type Bridge Unit	Gap Type	Maximum Gap Per Unit	Bridge Erection Time*
Ribbon Bridge	Wet	215 Meters	1 Hour/200 Meters
**Medium Girder Bridge	Dry	31.4 Meters	1.5 Hours/31.4 Meters 1 Hour/24.1 Meters .75 Hour/17 Meters

* Add 50 percent for periods of limited visibility or night time conditions.
** A double story (DS) bridge required for military load class (MLC) of 60.

Using the criteria from Table 3-9, a maneuver commander can determine if he has sufficient bridging assets to overcome the natural obstacle. If sufficient assets do not exist, then an infinite cost should be assigned to the arc containing the natural obstacle in the Dykstra algorithm for route selection. If sufficient bridging assets are available, then the following algorithm determines the delay time caused by the natural obstacle so that this delay can be added into Dykstra's modified algorithm. The algorithm uses the following variable definitions:

TD: Total Delay (hours).
BET: Bridge Erection Time (hours).
BCT: Bridge Crossing Time (hours).
GW: Gap Width (meters).
CCS: Constant Crossing Speed (9km/hour = 9000 meters/hour). Standard operating procedures from an actual bridge unit declare this CCS due to safety reasons.
VEH: Number of vehicles in maneuver unit to cross.
S: Unopposed speed of unit prior to encountering obstacle (km/hour).

The algorithm for determining natural obstacle delay is depicted:

$$TD = BET + BCT \tag{13}$$

BET = times defined in Table 3-9.

$$BCT = (GW/CCS) * VEH \tag{14}$$

The equations indicated above are based on one bridge being available to cross the maneuver force. If sufficient bridging assets exist and more than one bridge can be constructed, then VEH would be divided by the total number of bridges constructed assuming that each bridge will cross the same number of vehicles. The maneuver commander determines the emplacement of more than one bridge to reduce the crossing time.

If Dykstra's algorithm selects the arc containing the natural obstacle, then adjudication determines the obstacle effect. This adjudication reduces the mobility factor for the unit encountering the obstacle while it is traversing the arc between the two connector nodes which encompass the natural obstacle. This mobility factor scaling is computed as follows:

$$\text{Scaling Factor} = (GW/TD)/(S * 1000) \tag{15}$$

Hence, a maneuver unit's new mobility factor while traversing the arc containing the natural obstacle is the mobility factor of the terrain times the scaling factor. This scaling will reduce the mobility of the unit encountering the natural obstacle so that the time it takes the unit to traverse the arc will coincide with the actual delay time caused by the natural obstacle.

Since these natural obstacles are assumed to be in nonclose combat conditions, then the only delay is the time to overcome the natural obstacle. Additionally, in nonclose combat conditions, the natural obstacles have no attrition effects on the unit encountering the natural obstacle. An example illustrating the results of the natural

obstacle algorithms for a maneuver unit encountering a natural obstacle is depicted in Chapter 4 on page 82 of this document.

Bridging asset availability adjudication must also be performed prior to a bridge being employed. If sufficient bridging assets are not available, then an infinite cost is assigned to the arc containing the natural obstacle. Furthermore, once a bridging asset is employed, then the on hand quantity in the *engr.equipment.dat* file must be reduced to the appropriate quantity since the bridging asset is no longer available. Once the bridge asset is recovered, the quantity can be increased to reflect availability of the bridge asset.

3.7 Updating Dykstra Algorithm Costs for Route Determination.

As discussed in Chapter 2 of this thesis, JWAEP employs the Dykstra least cost path algorithm to determine a path for movement (if automatic path generation is selected) and the rate of movement along an arc for automatic and manual path generation. However, current methodology does not incorporate an obstacle's congestion effects or delay and attrition effects into the Dykstra algorithm for route selection and rate of movement. Incorporation of these effects is vital to realistically portraying the actions and effects of combat engineer units on the battlefield.

3.7.1 Criteria for Selection. Currently in JWAEP, the criteria for selecting a path or route using the Dykstra algorithm is to minimize the travel time where travel time is a function of the unit's speed, the terrain mobility factor along the arc, and the distance or length of the arc.. If, however, a unit has an order for *movement to contact* or *attack,* then the modified Dykstra algorithm will select the path which minimizes movement time and which contains a perceived enemy unit. To incorporate the effects of engineer mobility

and the reduction of enemy obstacles in a nonclose combat environment, the Dykstra algorithm for route selection must be modified to include the effects of obstacles: delay time to reduce or bypass the obstacle and the attrition received from discovering, reducing, and crossing the obstacle. Current JWAEP methodology employs the ATCAL model for close combat conditions and this thesis effort is only concerned with nonclose combat conditions. In accordance with current Army doctrine, a maneuver unit which is conducting unopposed (nonclose combat) movement will bypass all obstacles if possible [16:44]. Consequently, the modified Dykstra algorithm for route selection will include the delay time (obstacle discovery delay and bypass delay) and the front-line attrition of the force caused by obstacle discovery. The algorithms previously discussed for manmade obstacle delay (Equation (1)), manmade obstacle attrition (Equation (6)), and natural obstacle delay (Equation (13)) can be incorporated into the Dykstra algorithm to account for the additional obstacle effect costs. Equation (6) is divided by the total unit strength (personnel or equipment) prior to encountering the obstacle to obtain the fractional unit loss, a decimal scalar, caused by encountering the obstacle.

Since the Dykstra algorithm's current cost is the time to traverse an arc or path, the obstacle delay time can be added to this movement time to obtain a total time to traverse an arc which contains obstacles. This addition operation assumes that the depth of the obstacle complex is not computed twice. In computing the arc travel time, the distance used is the arc length less the depth of the obstacle complex. If an arc contains no obstacles, then the current Dykstra algorithm is sufficient and the obstacle delay time is zero. To incorporate the obstacle effect of attrition into the Dykstra algorithm, the

algorithm must be modified to consider both delay and attrition resulting from an obstacle encounter. This approach will use a two dimensional vector to denote the *lag* for a given arc.

A brief example of this modified Dykstra algorithm would be (8.5, .10) for traversing arc 213 and (7.5, .15) for traversing arc 223. In other words, selecting arc 213 as the path would produce a cost of 8.5 hours to traverse the arc and 10 percent attrition of the unit's personnel or equipment. Selecting arc 223 as the path would produce a cost of 7.5 hours to traverse the arc and 15 percent attrition of unit personnel or equipment.

An input parameter for relative weighting between delay and attrition is also required. This input parameter, w_i, is the JWAEP user's relative importance of attrition versus delay for unit $_i$.

In order to now select a route so that the *total cost* is minimized, the model will sum the delay time (in hours) for all possible routes or paths being considered so that a total delay time is obtained, and then, using a normalizing procedure, divide each route's delay time by the total summation of delay time for all routes to obtain a fraction of each route's delay in relation to the other routes' delays. Using the previous numerical values:

ARC 213: $8.5/(8.5 + 7.5) = .53$
ARC 223: $7.5/(8.5 + 7.5) = .47$

The modified normalized vector expressing delay and attrition would now appear in the following manner:

ARC 213: (.53, .10)
ARC 223: (.47, .15)

With the relative weighting input parameter, w_i, specified so that attrition and delay time can be compared according to a maneuver commander's priorities, the following heuristic is used to compute the total cost for traversing an arc. This heuristic assumes a normalized linear relationship between delay and attrition. Let:

A = Attrition fraction.
D = Delay fraction.
W_i = Weighting factor for unit $_i$ for attrition versus delay.
ATC = Arc total cost for unit $_i$

$$ATC = A * W_i + D * (1 - W_i) \tag{16}$$

Using the numerical values from the previous example and having the commander's attrition and delay weighting priorities for maneuver unit i with attrition as twice as important as delay, the computations for each arc's total cost are depicted:

ARC 213: (.10) * (.666) + (.53) * (1 - .666) = .24362
ARC 223: (.15) * (.666) + (.47) * (1 - .666) = .25688

Hence, ARC 213 possesses the least total cost, so it should be selected as the path or arc for the unit to traverse. Although ARC 213 has a greater time for traversing than the time for ARC 223, the weighting factor incorporating the maneuver commander's relative importance of attrition versus delay enabled ARC 213 to be selected as the path with the least total cost.

3.7.2 Perception of Obstacles. As previously discussed, the obstacle intelligence data is fused and a probability vector of existence, location and size is generated to form a perception of enemy obstacles. As more intelligence is collected and fused and as the encountering unit approaches closer to the obstacle, then the numeric values of the probability vector associated with ground truth will increase due to Bayesian updating.

However, this probability vector is always a perception until actually encountering the obstacle and performing adjudication.

Using this perception, all of the values in the delay and attrition algorithms are perceived values based on intelligence acquisition. The Dykstra algorithm for route selection is selecting paths for movement based on a perception of obstacle existence, location, size, and type. Additionally, the probability vector for obstacle existence is used in discovery loss attrition algorithms (equations 9 and 10) to adjust the initial discovery losses by the amount of obstacle intelligence information collected (probability vector). When a unit has encountered and exploited an obstacle, then "ground truth" is known and adjudication is conducted.

3.7.3 Ground Truth and Adjudication of Movement. When a maneuver encounters an obstacle and selects a mobility breaching tactic, then "ground truth" concerning the obstacle's attributes will be known and adjudication of the movement through or around the obstacle can be conducted. The algorithms for attrition and delay for manmade and natural obstacles as described previously will enable this adjudication. The only differences between perception and ground truth are the numerical values of the obstacles' attributes used in the algorithms and the use of the probability vector for determining discovery losses (equations 9 and 10). Additionally, adjudication also involves reducing the strength of the obstacle according to the mobility tactic employed. This obstacle strength reduction adjudication is only necessary if the encountering unit breaches the obstacle. Table 3-10 depicts the rates for obstacle strength reduction for the various obstacle classes. The values depicted in Table 3-10 are based on values obtained

from the VIC-EFAM model and also on the author's education, training, and 11 years of experience as a combat engineer officer [5:50].

Table 3-10 Obstacle Strength Reduction Rates

Obstacle Class	Percent Cleared Per Unit Crossing	OSR Fraction[4]
Natural	100	1.0
Manmade Point	100	1.0
Manmade Linear	25	.25
Manmade Area	10	.10

Consequently, if a maneuver unit perceives an area obstacle as a minefield and the maneuver commander decides to conduct an in-stride breach once encountering this obstacle, then adjudication would reduce the minefield's strength by 10 percent after the unit traverses the minefield. If a subsequent obstacle in the obstacle complex is a river and the maneuver commander employs ribbon bridge assets, then adjudication following the obstacle encounter would reduce the natural obstacle's strength by 100 percent. In other words, a river which is bridged becomes an ineffective natural obstacle until the bridge is recovered. The natural obstacle is depicted as ineffective because a river or gap is either bridged or not bridged. Although a unit's mobility factor is reduced due to crossing the bridge (Equation 15), the natural obstacle is considered ineffective when it has been bridged.

The mobility tactic doctrine and the algorithms depicted in this chapter are used in an obstacle complex scenario which is illustrated in the results and analysis of the next chapter.

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[4] The OSR fraction value for the manmade area obstacle was obtained from VIC-EFAM [5: 50]; all other OSR fraction values are based on the author's experience.

IV. RESULTS AND ANALYSIS

4.1 Determining Perceived Obstacle Attributes.

This section illustrates the acquisition of obstacle intelligence and the employment of the algorithm in the methodology section to perceive intelligence on possible existing obstacles in JWAEP.

JWAEP represents obstacles as "enemy unit icons" with specific field attributes. These obstacles are structured according to prototype data so that each specific obstacle which is employed is from an obstacle prototype class with known "TO&E" attributes [42:33-34]. Hence, the Bayesian process currently used in JWAEP can draw from these obstacle prototype TO&E attributes to produce a probability vector.

A maneuver unit operating in an offensive posture or conducting movement operations will position its assigned sensors in JWAEP according to METT-T and the commander's intent to obtain the best possible enemy intelligence information. When a sensor acquires information on an obstacle, it will receive and fuse some or all of the obstacle fields specified in the methodology section. Based upon what information is collected and fused, this knowledge is then compared to the existing obstacle prototype TO&E attributes. With this obstacle attribute information from the sensors, the application of a Bayesian process produces probabilities of obstacle existence. The best probability or closest prototype usually becomes the maneuver unit's perception of an obstacle's existence, type, size, and location; however, all possible inferences of all potential obstacle prototypes can be carried forward. As obstacle intelligence acquisition increases, then the closer the obstacle will compare to an obstacle prototype and the

probabilities through the Bayesian process will increase. Obtaining a probability perception of 1.0 would be impossible because the exact location (center of mass and all vertices) of the obstacle would have to be obtained.

This obstacle intelligence process also applies to natural obstacles. However, a majority of the natural obstacle information is already available to both sides from the JWAEP terrain data base.

Since this intelligence acquisition process is already in JWAEP, only the obstacle prototypes and attributes need to be implemented or changed. These field specification changes have no impact on the verification of the process since the process for acquiring obstacles is the same process for acquiring enemy units.

4.2 Scenario for Obstacle Effects.

Table 4-1 illustrates the effects of obstacles on an encountering unit and verifies the equations developed in Chapter 3. A realistic JWAEP scenario of an obstacle complex (Table 4-1) applies the delay, attrition, and arc total cost equations developed in Chapter 3 so the obstacle effect equation results can be analyzed. Additionally, this obstacle complex scenario allows the testing and verification of parameter values. Although the parameter values are at their extremes, these values illustrate the range of conditions of obstacles and units which could occur in a realistic combat situation. The units expressed in Table 4-1 are kilometers (OD, OF) and mines per linear meter (MFD), unless otherwise stated.

Table 4-1 Undiscovered Obstacle Complex Scenario

OBSTACLE COMPLEX PARAMETERS:

OBS (j)	CLASS TYPE	CLASS (i)	TACTIC	OD	OF	MFD	P(OBS EXIST)
1	Tank Ditch	2	Bypass	.02	1.2	N/A	.80
2	Minefield	3	Bypass	.75	1.0	1.0	.65
3	River	N/A	Breach	.05	N/A	N/A	N/A
4	Minefield	3	Breach	1.0	.50	.70	.50
5	Wire	2	Bypass	.10	.20	N/A	.90
6	Log Crib	1	Bypass	.01	.01	N/A	.25
7	Minefield	3	Bull	2.0	3.0	.20	.20
8	Minefield	3	Bypass	1.8	2.5	.50	.35
9	Tank Ditch	2	Breach	.02	.80	N/A	.75
10	Minefield	3	Bull	.20	.30	2.0	.95
11	Dry Gap	N/A	Breach	.03	N/A	N/A	N/A

Obstacles 2, 4, 7, 8, and 10 contain 7500, 1500, 5000, 3500 and 3000 mines respectively.

UNIT PARAMETERS:

Unit Type: Heavy Mechanized Battalion
UFW = .6 KM
UD = 1.2 KM
R = .671 KM
S = 15 KM/HR
CUS = 750 soldiers and 125 pieces of equipment

ADDITIONAL PARAMETERS:

Normal arc movement time = 6.5 hours for arc 132
Maneuver commander's priorities = attrition is 3 times more important than delay
Arc 132 contains obstacle complex depicted above
Arc 142 is an alternate movement arc containing no obstacles and the movement time is 28 hours
Arc 152 is an alternate movement arc containing no obstacles and the movement time is 41 hours

4.3 Results Due to Overcoming Obstacles.

The following sections illustrate the equation results for manmade and natural obstacle delay and attrition effects due to encountering the obstacle complex depicted in

the scenario in Table 4-1. These results are produced from the methodologies, procedures, and equations identified and discussed in Chapter 3.

4.3.1 Delay Results Due to Overcoming Manmade Obstacles. As specified in the methodology section, obstacles have a variety of delay effects on a maneuver unit and these effects are a function of the obstacle class and type, the size of the obstacle, and the mobility tactic employed by the encountering unit.

Using equations 1 - 4 from the methodology section and a variety of attribute parameters, delay times are calculated from the data in Table 4-1.

Equation (1): $TD = \Sigma(DD_j + BD_j + BT_j + TP_j)$(Page 52).
Equation (2): $BD_j = (OD_j + OF_j/2)/(FBD_j * S)$(Page 53).
Equation (3): $BT_j = OD_j/(FBD_j * S)$(Page 54).
Equation (4): $TP_j = [((2 * R) + OD_j) * (1\text{-}OSR_j)] * [(1/(S * FCD_j))\text{-}(1/S)]$(Page 54).

The delay results for the scenario are depicted in Table 4-2..

Table 4-2 Obstacle Complex Delay Time Results

OBST(j)	* DD(Table 3-6)	* FBD(Table 3-7)	* FCD(Table 3-8)	Bypass Delay	Bull Through	Time Penalty	Total Delay
1	1.0	.5	N/A	.08	N/A	N/A	1.08
2	2.0	.3	N/A	.28	N/A	N/A	2.28
3**	N/A	N/A	N/A	N/A	N/A	N/A	.94
4	.75	.05	.56	N/A	1.33	.28	2.36
5	1.0	.5	N/A	.03	N/A	N/A	1.03
6	.25	.8	N/A	.001	N/A	N/A	.251
7	.25	.05	.56	N/A	2.67	.40	3.32
8	2.0	.3	N/A	.68	N/A	N/A	2.68
9	.50	.08	.75	N/A	.02	.12	.64
10	.25	.05	.56	N/A	.27	.18	.7
11**	N/A	N/A	N/A	N/A	N/A	N/A	1.82

* Tables 3-6, 3-7, and 3-8 are depicted on pages 53, 53, and 54 respectively.
** Natural obstacle delay calculations are depicted in Section 4.3.3.

Using the procedures in Chapter 3, the time delays depicted in Table 4-2 are only applicable for the following mobility tactics:

BD_j: Bypass tactic only.
BT_j: Breach and bull-through tactics only.
TP_j: Breach and bull-through tactics only.

Using equation (1) and the results from Table 4-2, the total obstacle complex delay, TD = 17.1 hours. This result illustrates computed delay times with different ranges on obstacle types, sizes, and mobility tactics.

<u>4.3.2 Attrition Results Due to Overcoming Manmade Obstacles.</u> As illustrated in Chapter 3, manmade obstacles have an attrition effect on an encountering unit. This effect consists of a discovery loss and if a bull-through technique is employed, a bull-through loss. Attrition is a function of a variety of parameters and the losses of equipment and personnel reflect the total unit losses. For the obstacle complex scenario depicted in Table 4-1, equipment losses are initially computed using equations 6 - 12 from the methodology section and personnel losses are then calculated once the equipment losses are calculated.

Equation (6): $TL = \sum_{j=1}^{n}(DL_j + BTL_j)$(Page 59).
Equation (7): $DOU_j = CUS_j / (UD * UFW)$(Page 60).
Equation (8): $FLD_j = [1/DOU_j]^{.5}$(Page 61).
Equation (9): $DL_j = [1/FLD_j] * \text{Minimum}[UFW, OF_j] * [1 - P(OBS\ EXIST)_j]$(Page 61).
Equation (10): $DL_j = MFD_j * \text{Minimum}[UFW, OF_j]*$ (1 soldier or piece of equipment per mine) $* [1 - P(OBS\ EXIST)_j]$(Page 61).
Equation (11): $ROWS_j = MINES_j / (MFD_j * OF_j)$(Page 64).
Equation (12): $BTL_j = \{DL_j / [1-P\ (OBS\ EXIST)_j]\} * \text{Minimum}\ [(UD/FLD_j), ROWS_j] - DL_j$(Page 64).

The attrition results for the obstacle complex scenario are depicted in Table 4-3.

Table 4-3 Obstacle Complex Attrition Results

OBSTACLE (j)	CUS	DOU	FLD	MFD ≥ 1/FLD	EQUATION	DL	BTL	TL
2	125	.0002	75.9	YES	9	2.8	N/A	2.8
4	122	.0002	76.8	YES	9	3.3	N/A	3.3
7	119	.0002	77.8	YES	9	6.2	58.1	64.3
8	55	.00008	114.5	YES	9	3.4	N/A	3.4
10	51	.00007	118.8	YES	9	.13	12.7	12.9

The total loss for the obstacle complex: $TL = \sum_{j=1}^{n}(DL_j + BTL_j) = 86.67$.

The results in Table 4-3 illustrate the unit equipment losses when encountering various minefields in an obstacle complex. The obstacle complex scenario used minefields with different sizes, densities, and mines to interact with a unit employing all three mobility tactics to verify the attrition methodology and equations depicted in Chapter 3. The total equipment losses in Table 4-3 are realistic and verifiable results considering the different values of each input variable in the attrition algorithms. This verification is reflected in Section 4.5.

If total personnel losses are required, then existing information is used to compute these losses. Since the total unit strength is 750 soldiers and 125 pieces of equipment, then 750 divided by 125 yields 6 soldiers per piece of equipment. From Table 4-3, 86.67 equipment losses occurred, so the personnel losses become:

Personnel Losses = (86.67 equipment losses) * (6 soldiers/piece of equipment).
Personnel Losses = 520 soldiers lost.

This representation of calculating personnel losses from equipment losses is realistic because a heavy maneuver force is mounted in its equipment. When this unit encounters a minefield and a vehicle impacts a mine, it is assumed that the vehicle is a loss. Since the vehicle is a loss, then the crew of the vehicle is also a loss. If the force

were not mounted, then attrition calculations using the equations in Chapter 3 should use the personnel strength and not equipment strength.

4.3.3 Delay Result for Overcoming Natural Obstacles. Natural obstacles in a nonclose combat environment produce only a delay effect to an encountering unit. This delay is a function of the bridge erection time and the time which it takes to cross the unit over the natural obstacle. These delays are computed using equations (13) and (14) from the methodology section.

Equation (13): TD = BET + BCT
Equation (14): BCT = (GW/CCS) * VEH

Using the obstacle complex scenario depicted in Table 4-1, the natural obstacle delay calculations for the two natural obstacles are illustrated.

Natural Obstacle 3 (River):
BET = (1 hour/200 meters) * (50 meters)
BET = .25 hours
BCT = [(50 meters)/(9000meters/hour)] * (125 vehicles)
BCT = .69 hours
TD = BET + BCT
TD = .25 hours + .69 hours
TD = .94 hours

Natural Obstacle 11 (Dry Gap)
BET = (1.5 hours/31.4 meters) * (30 meters)
BET = 1.4 hours
BCT = [(30 meters)/(9000 meters/hour)] * (125 vehicles)
BCT = .42 hours
TD = BET + BCT
TD = 1.4 hours + .42 hours
TD = 1.82 hours

These natural obstacle effects illustrate the delay a unit incurs when encountering a natural obstacle during movement. Additionally, these results are reflected in Table 4-2 so that a total obstacle complex delay, TD, could be computed.

4.3.4 Dykstra Algorithm Cost Results for Overcoming Obstacles. Using the obstacle complex scenario depicted in Table 4-1 and the delay and attrition results from sections 4.3.1 - 4.3.3, the total cost for movement along an arc is computed to reflect the effects of the obstacles on an encountering unit's movement path. Using the methodology from Chapter 3 and the modified Dykstra total cost algorithm (equation 16), a total cost for arc movement can be computed.

Equation (16): $ATC = A * W_i + D * (1 - W_i)$

Using the scenario information and the delay and attrition results, each of the three arc's total delay and attrition are calculated:

ARC 132: DELAY = 6.5 hours + 17.1 hours = 23.6 hours
ATTRITION = 520 soldiers

ARC 142: DELAY = 28 hours
ATTRITION = 0

ARC 152: DELAY = 41 hours
ATTRITION = 0

Normalizing the delay times using the procedures in Chapter 3:

ARC 132 = 23.6/ (23.6 + 28 + 41) = .25
ARC 142 = 28/ (23.6 + 28 + 41) = .30
ARC 152 = 41/ (23.6 + 28 + 41) = .45

To obtain the fractional unit loss of the maneuver unit encountering the obstacle complex, the procedures in Chapter 3 are used:

Fractional Unit Loss = TL/CUS = 520/750 = .693

The modified normalized vectors depict delay and attrition coefficients:

ARC 132: (.25, .69)
ARC 142: (.30, 0)
ARC 152: (.45, 0)

Using equation (16) and the maneuver commander's priorities from the scenario in Chapter 4, the total costs for each arc are illustrated:

Attrition is 3 times more important than delay: $W_i = .75$

ARC 132: ATC = (.69) * (.75) + (.25) * (1 - .75) = .58
ARC 142: ATC = (0) * (.75) + (.30) * (1 - .75) = .075
ARC 152: ATC = (0) * (.75) + (.45) * (1 - .75) = .113

Since ARC 142 has the least arc total cost, ARC 142 should be selected for the heavy battalion to maneuver along. Although ARC 142 has a greater time for traversing than the time for ARC 132, the weighting factor incorporating the maneuver commander's relative importance of attrition versus delay drove ARC 142 to be selected as the path with the least *total cost.*

Consider an adjustment to the scenario where ARC 142 now contains an obstacle complex which produces an additional delay of 4 hours and an attrition of 175 soldiers and ARC 152 contains an obstacle complex which produces an additional delay of 20 hours and an attrition of 30 soldiers. Then the adjusted calculations are depicted:

ARC 132: DELAY = 6.5 hours + 17.1 hours = 23.6 hours
ATTRITION = 520 soldiers

ARC 142: DELAY = 4 hours + 28 hours = 32 hours
ATTRITION = 175 soldiers

ARC 152: DELAY = 20 hours + 41 hours = 61 hours
ATTRITION = 30 soldiers

Normalizing the delay times using the procedures in Chapter 3:

ARC 132 = 23.6/ (23.6 + 32 + 61) = .20
ARC 142 = 32/ (23.6 + 32 + 61) = .28
ARC 152 = 61/ (23.6 + 32 + 61) = .52

To obtain the fractional unit loss of the maneuver unit encountering the different obstacle complexes along each arc, the procedures in Chapter 3 are used:

Fractional Unit Loss = TL/CUS
ARC 132: Fractional Unit Loss = 520/750 = .69
ARC 142: Fractional Unit Loss = 175/750 = .23
ARC 152: Fractional Unit Loss = 30/750 = .04

The modified normalized vectors depict delay and attrition coefficients:

ARC 132: (.20, .69)
ARC 142: (.28, .23)
ARC 152: (.52, .04)

Using equation (16) and the maneuver commander's priorities from the scenario in Chapter 4, the total costs for each arc are illustrated:

Attrition is 3 times more important than delay: $W_i = .75$

ARC 132: ATC = (.69) * (.75) + (.20) * (1 - .75) = .568
ARC 142: ATC = (.23) * (.75) + (.28) * (1 - .75) = .243
ARC 152: ATC = (.04) * (.75) + (.52) * (1 - .75) = .160

Since ARC 152 has the least arc total cost, ARC 152 would be selected for the heavy battalion to maneuver along. Although ARC 152 now possesses a significantly higher travel time than the other arcs, the attrition along this path meets the maneuver commander's priorities and is significantly lower than the other arcs. Because the modified Dykstra algorithm accounts for costs due to delay and attrition based on the priorities of the commander, obstacle delay and attrition effects can decidedly affect the route selection for movement.

4.4 Tactical Breaching Decision Results.

The doctrine alternatives established for the mobility tactic in JWAEP are bypass, in-stride breach, and bull-through. Under nonclose combat conditions, an obstacle in

JWAEP will always be bypassed unless the obstacle conditions do not permit a bypass operation. Such conditions would include an obstacle which is situated in natural terrain such that a bypass route is untenable, or a natural obstacle (river) which is running perpendicular to the desired unit movement direction on an arc. During these conditions, the bypass tactic is impossible to implement so the unit should implement an in-stride breach tactic. The effects of these tactics are the delay and attrition factors developed in the methodology section of this document.

In analyzing the tactical decision process for implementing mobility tactics on an obstacle in JWAEP, it is readily apparent that enemy obstacles employed in nonclose combat conditions will probably be bypassed upon discovery. Considering the delay and attrition results depicted in Tables 4-2 and 4-3 from the obstacle complex scenario, it is clear that the bypass tactic is the dominant and preferred mobility tactic under nonclose combat conditions. The delay times and losses to an encountering unit not employing a bypass tactic are significantly greater than the delay times and losses received when using a bypass tactic. Consequently, the doctrinal procedures identified in Chapter 3 for mobility tactic employment are valid for nonclose combat conditions in JWAEP. However, the results reflected in Tables 4-2 and 4-3 also illustrate a requirement for JWAEP decision rules to employ the proper mobility tactic. These decision rules are discussed in the recommendations section of Chapter 5.

The obstacles, once discovered and bypassed, are *flagged* so that follow-on forces do not receive initial discovery losses or initial discovery delays. The strength of these obstacles will not be reduced due to implementing a bypass tactic, so it is possible for

numerous discovered obstacles to remain on the JWAEP battlefield while maneuver forces follow alternate routes around these obstacles.

This JWAEP representation of bypassing obstacles and the effects of the bypass tactic are realistic when compared to an actual real world implementation of the bypass tactic and its effects. Several after action reports state that during Operations Desert Shield/Storm, the majority of the extensive Iraqi obstacle system was bypassed with a flanking movement and these obstacles remained in place while the theater maneuver elements continued toward their objectives. This example illustrates current mobility doctrine and the priorities placed on flexible movement and preservation of the force.

4.5 Verification of Results.

Verification of the results obtained from the algorithms in Chapter 3 and the scenario in Table 4-1 involves an analysis of the algorithms and results. This analysis includes testing the algorithms with input variables to determine if the results change logically according to incremental changes in the input variables. The algorithms requiring verification include the delay and attrition effects from manmade obstacles, the delay effects from natural obstacles, and the Dykstra algorithm cost equation. Table 4-4 reflects the verification effort for each of these algorithms and the following paragraphs illustrate examples of conducting this verification.

Verification of the manmade obstacle delay and attrition algorithms is accomplished by varying the size of the obstacle (delay effect) and the density of the unit (attrition effect). As the size of a obstacle is increased, the delay time is expected to

increase; as the density of a unit is increased, the losses are also expected to increase.

Using the scenario in Table 4-1 and the results obtained for obstacle 8 (minefield):

Obstacle 8 (Minefield)
- OF_8 = 2500 meters
- OD_8 = 1800 meters
- UFW = 600 meters
- UD = 1200 meters
- Total Delay = 2.68 hours (Table 4-2, page 79)
- Total Losses = 3.4 equipment losses (Table 4-3, page 81)

Using the same conditions for obstacle 8 and increasing only the minefield size to analyze the effect on delay yields:

Obstacle 8 (Minefield)
- OF_8 = 3000 meters
- OD_8 = 2400 meters
- Total Delay = 2.87 hours

Using the same conditions for obstacle 8 and increasing only the unit density to analyze the effect on attrition yields:

- UFW = 1000 meters
- UD = 2000 meters
- Total losses = 3.5 equipment losses

As expected, the losses increase as the density of the unit increases and the delay increases as the minefield size increases. Consequently, the manmade obstacle effect algorithms are yielding results consistent with expected results.

Verifying the natural obstacle delay algorithm is accomplished by varying the width of the gap. As the width of a dry or wet gap is increased, the delay time is expected to increase. Using the scenario in Table 4-1 and the results obtained for obstacle 3 (page 82), the following is achieved.

Obstacle 3 (River)
GW = 50 meters
BET = .25 hours
BCT = .69 hours
TD = .94 hours

Using the same conditions for obstacle 3 and increasing only the gap width to analyze the effect on delay yields:

Obstacle 3 (River)
GW = 100 meters
BET = (1 hour/200 meters) * (100 meters)
BET = .50 hours
BCT = [(100 meters)/9000 meters/hour)] * (125 vehicles)
BCT = 1.39 hours
TD = .50 hours + 1.39 hours
TD = 1.89 hours

As expected, the delay time increases as the width of the gap increases. Consequently, the natural obstacle effect algorithm yields results which are consistent with expected results.

Verifying the Dykstra algorithm cost equation was previously accomplished in Section 4.3.4 on pages 83 - 85. By increasing the number of obstacles along a movement arc, the total cost of the arc is expected to increase. Using the scenario in Table 4-1 and the results obtained for ARC 142 on pages 83 - 84:

ARC 142: DELAY = 28 hours
ATTRITION = 0
ATC = .075

Using the same conditions for ARC 142 and adding an obstacle complex to this arc (pages 84 - 85) to analyze the effect on total cost yields:

ARC 142: DELAY = 32 hours
ATTRITION = 175 soldiers
ATC = .243

As expected, the arc total cost increases as obstacles are added to the arc. Consequently, the Dykstra algorithm cost equation yields results which are consistent with expected results.

Table 4-4 reflects the complete verification effort for the four methodologies presented and incorporates flucuations of all input variables in each of the methodologies.

Table 4-4 Verification of Methodologies

Algorithm	Input Parameter	Parameter Flucuation Direction	Expected Result Direction	Actual Result	Actual Result Direction	Verified
Manmade Delay	OD	Increase	Increase	2.83	Increase	Yes
Manmade Delay	OD	Decrease	Decrease	2.50	Decrease	Yes
Manmade Delay	OF	Increase	Increase	2.73	Increase	Yes
Manmade Delay	OF	Decrease	Decrease	2.62	Decrease	Yes
Manmade Delay	R	Increase	Increase	0.72	Increase	Yes
Manmade Delay	R	Decrease	Decrease	0.55	Decrease	Yes
Manmade Delay	OSR	Increase	Decrease	0.55	Decrease	Yes
Manmade Delay	OSR	Decrease	Increase	0.76	Increase	Yes
Manmade Attrition	MFD	Increase	Increase	2.90	Increase	Yes
Manmade Attrition	MFD	Decrease	Decrease	2.60	Decrease	Yes
Manmade Attrition	UFW	Increase	Increase	4.50	Increase	Yes
Manmade Attrition	UFW	Decrease	Decrease	2.26	Decrease	Yes
Manmade Attrition	OF	Increase	Increase	13.8	Increase	Yes
Manmade Attrition	OF	Decrease	Decrease	12.8	Decrease	Yes
Manmade Attrition	P(Obs Exist)	Increase	Decrease	0.80	Decrease	Yes
Manmade Attrition	P(Obs Exist)	Decrease	Increase	5.60	Increase	Yes
Manmade Attrition	MINES	Increase	Increase	67.2	Increase	Yes
Manmade Attrition	MINES	Decrease	Decrease	51.3	Decrease	Yes
Natural Delay	GW	Increase	Increase	1.90	Increase	Yes
Natural Delay	GW	Decrease	Decrease	0.48	Decrease	Yes
Natural Delay	VEH	Increase	Increase	1.36	Increase	Yes
Natural Delay	VEH	Decrease	Decrease	0.53	Decrease	Yes
Weighted Dykstra	A	Increase	Increase	0.63	Increase	Yes
Weighted Dykstra	A	Decrease	Decrease	0.29	Decrease	Yes
Weighted Dykstra	D	Increase	Increase	0.64	Increase	Yes
Weighted Dykstra	D	Decrease	Decrease	0.54	Decrease	Yes

The algorithms presented in Chapter 3 for representing the effects of obstacles and calculating the total movement cost along an arc yield verifiable and consistent results as reflected in Table 4-4. These results will be analyzed for sensitivity of parameters in the subsequent section.

4.6 Sensitivity Analysis of Results.

Using the scenario depicted in Table 4-1, the methodologies proposed in Chapter 3 for representing the effects of manmade and natural obstacles were previously verified using realistic input parameters and analyzing the output from the algorithms. Specifically, an analysis of the results from the manmade obstacle delay and attrition algorithms, the natural obstacle delay algorithms, and the modified Dykstra total cost algorithm yields realistic and verifiable effects. Using the obstacle complex scenario and the results produced provides conclusive evidence that these algorithms yield realistic results.

In examining the manmade obstacle delay effect results, it is evident from Table 4-2 that employing a bull-through technique will consistently double the total delay time as compared to bypassing the obstacle. Under nonclose combat conditions, these results reflect the doctrine requirement for seeking a bypass route around all obstacles. Additionally, the attrition effects from these same obstacles also produce similar conclusions. Table 4-3 illustrates a significant increase in unit losses when employing a bull-through technique through a minefield. In retrospect, the use of the bypass tactic yields the least number of discovery losses and these losses decrease proportionally to the amount of acquired obstacle intelligence. Additionally, these algorithmic results were confirmed by other senior engineer officers and passed the author's common sense check

which is based upon firsthand experience of conducting these mobility operations during actual training exercises in Korea. A comparison of the results from manmade obstacle effects to results achieved from the VIC-EFAM model is illustrated in Table 4-5. The similarities in the results depicted in Table 4-5 also validate the methodologies presented in Chapter 3 of this thesis.

An analysis of the natural obstacle delay effect results produces results very similar to the expected bridging and crossing times depicted in Army Field Manual (FM) 5-34. Although the expected or standard bridging and crossing times in FM 5-34 are based on several varying conditions (combined arms support, close versus nonclose combat conditions, river and river bank conditions, weather) as opposed to the use of generic conditions (type of gap, width of gap, nonclose combat) in the JWAEP algorithm, the obtained results on page 82 are consistent with published expected results [17:7-5 --7-7; 7-32 --7-48]. Furthermore, these results are consistent with VIC-EFAM results for river crossing effects using higher resolution algorithms with varying environmental conditions (intensity of combat, visibility, weather) [29:C1-C3, D1]. Table 4-5 depicts a comparison of the natural obstacle results for the river (obstacle 3) in the scenario provided (Table 4-1) with the results from the VIC-EFAM model and published Army manuals.

Table 4-5 Validation of Results for Obstacle Effect Representation

	RESULTS		
ALGORITHM	JWAEP	VIC-EFAM	PUBLISHED MANUALS
Natural Obstacle Delay	.94 hours	1.00 hours	.75 hours
Manmade Obstacle Delay	.70 hours	0.65 hours	N / A

The times depicted from the various sources in Table 4-5 are similar in quantity and validate the results achieved from the proposed JWAEP algorithms.

An analysis of the modified Dykstra total cost algorithm results on pages 83-85 reflects reasonable results which now enable the *total cost* to account for obstacle effects and the priorities of the maneuver commander. Although the results realistically incorporate attrition and delay into the total cost computation, it is extremely difficult to normalize *apples and oranges* into one quantifiable category (total cost) from which decisions are made. Equation (16) represents the normalization; however, this equation can produce bias results since the attrition coefficients in the vectors (assumes multiple routes) do not sum to one, but the time coefficients in the vectors do sum to one. This phenomena is due to the normalization of the time coefficients and the lack of normalization of the attrition coefficients. The time coefficient is easily normalized because an arc which contains no obstacles still possesses an associated time for traversing the arc. Each arc's total cost vector will possess a value which is greater than zero for the time coefficient. Attrition, however, only occurs along arcs where obstacle complexes containing minefields exist. Therefore, if the attrition coefficients were normalized, then incorrect conclusions can be made from equation (16). For example, if movement could occur along three potential arcs (Arc 1, 2, and 3), and ARCs 1 and 2 contained no obstacles but possessed an extremely high travel time and ARC 3 contained one small minefield which attrited 0.01 percent of the unit but possessed an insignificantly small travel time, it is possible using equation (16) to not select ARC 3 if the attrition coefficients were normalized.

$$\text{ARC 1: ATC} = (0) * (.75) + (.45) * (1 - .75) = .1125$$

ARC 2: ATC = (0) * (.75) + (.40) * (1 - .75) = .1
ARC 3: ATC = (1) * (.75) + (.05) * (1 - .75) = .7625

Normalizing attrition in this case yields an attrition coefficient of 1.0 for ARC 3 and forces ARC 3 not to be selected. Due to this potential error, the modified Dykstra total cost methodology does not follow a normalization of the attrition coefficients. As a result, these attrition coefficients consistently seem to be smaller than the time coefficients. Consequently, a commander's actual weighting of attrition being five times greater than delay may in reality only be 5/3 times more important than delay due to the relative numerical difference which exists between the attrition and time coefficients. However, for the scenario depicted in Table 4-1 and the multiple results achieved, this "apple and orange comparison" between attrition and delay using realistic commander's priorities had no effects on the resultant path selected for movement.

Nevertheless, to correct this potential error in the relative difference between the time coefficients and the attrition coefficients, an absolute attrition threshold criteria will be used to compensate for the disparity between the coefficients. This absolute attrition threshold will be established by the model user; however, a default setting of 10 percent is established based on the author's knowledge of allowable unit attrition under nonclose combat conditions. Assuming a default setting of 10 percent, if a unit's perceived attrition along an arc is less than 10 percent of the current unit strength, then the existing modified Dykstra total cost algorithm (Equation 16) presented in Chapter 3 is used. If, however, a unit's perceived attrition along an arc is greater than or equal to 10 percent of the current unit strength, then the arc is assigned an infinite cost so that it is not selected for movement.

In summary, the results obtained from the methodology and algorithms presented in Chapter 3 are consistent and comparable with actual published results, with other model's results, and with the author's common sense results (Table 4-5). An analysis of the algorithms' results identified a minor discrepancy in the modified Dykstra total cost algorithm, the employment of the proper mobility tactic, and the need for potential follow-on work. Specifically, the results identified the potential discrepancy with not normalizing the attrition coefficient and the need for JWAEP decision rules to employ the proper mobility tactic under the correct conditions. The recommendations section in Chapter 5 identifies decision rules to properly employ mobility tactics in JWAEP and further discusses the required follow-on work.

V. RECOMMENDATIONS AND CONCLUSIONS

5.1 Summary.

Chapter 3 developed the methodology to accurately represent the mobility effects of combat engineers in the JWAEP model. The solution techniques incorporated theater-level mobility engineer effects into JWAEP using Army doctrine and existing concepts from other combat models. These solution techniques included:

1) The existing JWAEP intelligence architecture serves as a foundation to develop the obstacle intelligence acquisition process for perceptions of potential enemy obstacles.

2) Manmade obstacle effect algorithms use existing doctrine and the concepts from the VIC-EFAM model to represent the delay and attrition effects from obstacles.

3) Natural obstacle effect algorithms use existing doctrine and JWAEP architecture to represent the delay effects of natural obstacles and their impediments to a maneuvering force.

4) The Dykstra algorithm incorporates modifications to yield a total arc cost which reflects the obstacle effects of attrition and delay. This modified Dykstra algorithm enables the selection of routes based on costs of movement times, attrition, and delay and the incorporation of a maneuver commander's priorities.

5) The representation of various mobility tactics under nonclose combat conditions in JWAEP is doctrinally based and reflects the employment priorities of BYPASS, BREACH, and BULL-THROUGH.

The obstacle complex scenario and algorithmic results depicted in Chapter 4 verify the functionality and doctrinal conformity of the solution techniques and allow analysis and conclusions to be made. The next section illustrates the conclusions of this thesis effort.

5.2 Conclusions.

The proposed methodology and solution techniques discussed in Chapter 3 provide doctrinally based mobility effects to explicitly model mobility engineer effects in JWAEP. The obstacle intelligence acquisition process efficiently links with the existing JWAEP intelligence architecture to represent the uncertainty of engineer effects. Additionally, the algorithms for delay and attrition effects for manmade obstacles doctrinally quantify the effects of obstacles and permit these obstacles to impede movement. The incorporation of natural obstacles and their effects into JWAEP enable movement limitations throughout a JWAEP scenario; previously, movement along arcs containing these natural impediments was not permitted due to lack of obstacle effect representation. Lastly, the tactical mobility breaching decision process incorporated into JWAEP explicitly represents the engineer doctrine for negotiating obstacles.

In conclusion, the incorporation of perception and the existing JWAEP intelligence acquisition architecture maintains the stochastic nature for JWAEP's representation of all mobility effects (delay and attrition). Additionally, the algorithms for representing these mobility effects are also ground truth adjudication algorithms which could be included in other theater-level combat models and which could also serve as decision support tools for the United States Army Engineer School. The following sections provide

recommendations for implementing the methodology and solution techniques into the JWAEP model.

5.3 Recommendations.

The subsequent recommendations allow methodology implementation into the JWAEP model. This section provides suggestions for linking the current JWAEP architecture with the methodology proposed in Chapter 3 and concludes with some possible follow-on work to this thesis.

5.3.1 Linking the Obstacle Intelligence Acquisition Process. Since the JWAEP architecture is currently structured to handle perception of opposition units, the linking of the obstacle intelligence acquisition process into the current intelligence structure is significantly simplified. The linkage is further simplified by the manmade obstacle complex instance representation as an "enemy unit icon" in JWAEP [42:33, 35-36]. The attributes specified for a manmade obstacle are similar in nature and architecture to the attributes of an enemy unit. The attributes or fields of a manmade obstacle in the model's *complex.dat* file, define the characteristics of each obstacle (location, size, type) [42:33-36]. Additionally, the "TO&E" or attribute characteristics for obstacle prototypes need to be established in JWAEP so that intelligence on obstacle sightings feeds the Bayesian process for comparison against similar obstacle prototypes to develop a perception (probability vector) of an obstacle's existence, size, type, and location.

Once the obstacle prototype attribute characteristics are developed and the obstacles are input into the scenario, then acquisition and perception of enemy obstacles

can occur as well as Bayesian updates of the perceptions using existing JWAEP sensors and the sensor fusion process [45:65].

5.3.2 Linking the Obstacle Effects to the Dykstra Algorithm. The incorporation of the manmade obstacle effects (delay and attrition) and the natural obstacle effect (delay) into the Dykstra algorithm to determine a total cost for arc movement is developed in section 3.7 of this document and shown below.

$$\text{Equation (16): } ATC = A * W_i + D * (1 - W_i)$$

If an arc does not contain manmade or natural obstacles, then the existing Dykstra algorithm calculates the total arc cost (movement time).

A maneuver unit trying to select a route for movement uses a perception of obstacles (probability vector) from the obstacle intelligence acquisition process for each alternative route to affect the perceived unit losses. The equations specified in the methodology section for obstacle delay and attrition effects and for the total arc cost determine the selection of the least cost path. Additionally, using the attrition threshold criteria established in the sensitivity analysis section of Chapter 4, a route is assigned an infinite cost and alleviated from selection if the perceived attrition exceeds the established threshold. Once a route is selected, the travel time calculations from the Dykstra algorithm reduce the mobility factor of the unit traversing the arc. Once a unit encounters an obstacle along the arc of movement and it determines a mobility tactic from the decision rule set, then adjudication permits the assessment of appropriate delays and unit losses in accordance with the equations from Chapter 3 using ground truth obstacle attribute data, not perceived obstacle data.

5.3.3 Linking the Tactical Decision Process for Mobility Tactics. The employment of various mobility tactics during nonclose combat conditions is specifically addressed in engineer doctrine [5:44, 46] and modeled in JWAEP using a decision rule set based on that doctrine. Incorporating these decision rules into JWAEP involves a linkage to the existing JWAEP architecture.

The following decision rules need to be incorporated into the JWAEP command, control, communications and intelligence (C3I) process to ensure doctrinally correct tactics. The C3I process currently supports and applies the decision rules in JWAEP.

1) If an obstacle is perceived to exist, is manmade, and nonclose combat conditions exist, bypass the obstacle.

2) If an obstacle is perceived to exist, is manmade, and close combat conditions exist, utilize ATCAL for adjudication.

3) If an obstacle is perceived to exist, is natural, and nonclose combat conditions exist, employ an in-stride breach of the obstacle.

4) If an obstacle is perceived to exist , is natural, and close combat conditions exist, utilize ATCAL for adjudication.

Although this rule set only permits the employment of a bypass tactic for manmade obstacles in nonclose combat conditions, this representation is doctrinally realistic and valid. When nonclose combat conditions exist, a maneuver unit doctrinally seeks to bypass, breach, and then bull-through the obstacle. A majority of the time, the obstacle can be bypassed. The few instances which these obstacles cannot be bypassed are relatively insignificant, so this representation in JWAEP is unnecessary.

5.3.4 Follow-on Work. Mobility engineering and the explicit modeling of its effects in a nonclose combat environment is only a portion of the combat engineers' representation. Since close combat is currently modeled in JWAEP using ATCAL and similar COSAGE runs, the proper portrayal of combat engineer functions in a close combat environment is not realistically represented due to the limited effects depicted for engineers in COSAGE runs [42:40, 48]. A more representative modeling effort for depicting combat engineer effects in a close combat environment in JWAEP may be necessary. The engineer architecture illustrated in this thesis could be used as a foundation for engineer representation in close combat; however, the underlying assumptions in Section 3.3 and the uncertain factors in Section 3.6.3 would need to be reviewed. A decision analysis framework for representing the mobility effects in a close combat environment is outlined in Appendix D (Close Combat Decision Analysis Framework). Using a decision analysis framework permits the modeler to explicitly consider and analyze the numerous uncertainties of representing engineer tactics and effects in a close combat environment.

Due to JWAEP's previous lack of natural obstacle representation, the procedures identified in Chapter 3 now enable the representation of crossing dry and wet gaps under nonclose combat conditions. However, this natural obstacle representation is only a beginning to properly representing all of the effects of natural obstacles. The VIC-EFAM model provides a suitable foundation for modeling the effects of swimming and fording wet gaps and the crossing effects while under close combat conditions in JWAEP [29: 3-15].

The last follow-on work recommendation incorporates JWAEP's perception capability into the modified Dykstra total cost algorithm developed in Chapter 3. The current methodology only incorporates uncertainty or perception of obstacle existence in the attrition calculations. Further efforts could use the existing perception framework in JWAEP and the modified Dykstra algorithm to incorporate the uncertainty and perceptions associated with all obstacle effects so that each possible path which the Dykstra algorithm is considering has an associated probability or perception of obstacle ground truth. For example, if three arcs were being considered for movement and each arc had an associated perception (probability) for obstacles along the arc, then this perception could be accounted for along each arc by developing an overall expected value along each arc. This overall arc perception or expected value is used in the modified Dykstra total cost algorithm presented in Chapter 3 of this thesis to reflect the uncertainty and obstacle intelligence capabilities of a unit prior to selecting a route for movement.

APPENDIX A. ENGINEER ORGANIZATION

This appendix lists the engineer organizations, their basis for allocation and their mission statements.

Section I
Command and Control Elements

Engineer Unit	Normal Assignment	Normal Basis of Allocation	Organizational Mission Statement
Headquarters, Engineer Command	To Theater Army (TA)	1 per TA	To command, perform operational planning and supervision. To coordinate the activities of assigned or attached engineer brigades, groups, and other units engaged in construction, topographic activities, production of military geographic intelligence, and related activities.
HHC, Engineer Brigade (Theater Army)	To TA; attached to ENCOM	1 per 2 to 7 Engr Bn or 2 to 4 Engr Gp	To command assigned and attached units and coordinate, engineer activities. To plan and coordinate the operations of engineer units engaged in combat support, construction and rehabilitation of of facilities in support of a theater of operations.
HHC, Engineer Brigade (Corps or Airborne Corps)	To Corps	1 per corps	To command assigned and attached units and coordinate engineer activities. To plan and coordinate the operation of engineer units engaged in combat support, construction, and rehabilitation of facilities in support of a corps.
HHC, Engineer Group	To TA or corps; normally attached to Engr Bde	1 per 3 to 7 Engr Bns	To command assigned and attached units and coordinate engineer activities.

Engineer Unit	Normal Assignment	Normal Basis of Allocation	Organizational Mission Statement
Engineer Administrative and HQ Team	As required	As required	To provide command and administrative support for engineer composite units.

Section II
Engineer Battalions

Engineer Unit	Normal Assignment	Normal Basis of Allocation	Organizational Mission Statement
Engineer Battalion, Airborne Division	Organic to Airborne Division	1 per Airborne Division	To increase the combat effectiveness of the airborne division by accomplishing mobility, countermobility, and survivability tasks. To perform infantry combat rnissions when required.
Engineer Battalion, Heavy Division	Organic to Heavy Division	1 per Heavy Division	To increase the combat effectiveness of the heavy division by accomplishing mobility, countermobility, and survivability tasks. To perform infantry combat rnissions when required.
Engineer Battalion, Infantry Division (Light)	Organic to Infantry Division (Light)	1 per Infantry (Light)	To increase the combat effectiveness of the light infantry division by accomplishing mobility, countermobility, and survivability tasks. To perform infantry combat missions when required.
Engineer Battalion, Air Assault Division	Organic to Air Assault Division	1 per Air Assault Division	To increase the combat effectiveness of the air assault division by accomplishing mobility, countermobility, and survivability tasks. To perform infantry combat missions when required.
Engineer Battalion, Infantry Division	Organic to Infantry Division	1 per Infantry Division	To increase the combat effectiveness of the infantry division by accomplishing mobility, countermobility, and survivability tasks. To perform infantry combat missions when required.

Engineer Unit	Normal Assignment	Normal Basis of Allocation	Organizational Mission Statement
Engineer Combat Battalion, Corps	To corps; attached to Engineer Brigade or Group	3 per Division (except 1 per Heavy Division)	To increase the combat effectiveness of the corps by accomplishing mobility, countermobility, survivability, and sustainment engineering tasks. To reinforce divisional engineer units when required. To perform infantry combat missions when required. To participate in joint military operations when required.
Engineer Combat Battalion (Mechanized), Corps	To corps; attached to Engineer Brigade or Group	2 per Heavy Division	To increase the combat effectiveness of the corps by accomplishing mobility, countermobility, and survivability tasks. To reinforce divisional engineer units when required. To perform infantry combat missions when required. To participate in joint military operations when required.
Engineer Combat Battalion (Airborne/Light)	To corps or the Army element of a JTF	1 per Airborne or Infantry Division (Light)	To increase the combat effectiveness of the supported unit by accomplishing mobility, countermobility, survivability, and sustainment engineering tasks. To reinforce divisional engineer units when required. To perform infantry combat missions when required. To participate in joint military operations when required.
Engineer Combat Battalion, Heavy	To TA, corps, JTF, or CTF	As required up to 5 per Engr Gp	To increase the combat effectiveness of division, corps, and TA forces by accomplishing sustainment engineering tasks and limited mobility, countermobility, and survivability tasks. To construct, repair, and maintain MSRs, landing strips, buildings, structures, and utilities. To perform rear area security operations when required.
Engineer Battalion Topographic	To TA; attached to ENCOM	1 per TA	To provide engineer topographic support to theater elements.

Section III
Separate Engineer Companies

Engineer Unit	Normal Assignment	Normal Basis of Allocation	Organizational Mission Statement
Engineer Company, Separate Infantry Brigade	Organic to Separate Infantry Brigade	1 per Separate Infantry Brigade	To increase the combat effectiveness of the separate infantry brigade by accomplishing mobility, countermobility, survivability, and sustainment engineering tasks. To perform infantry combat missions when required.
Engineer Company, Armored Cavalry Regiment	Organic to Armored Cavalry Regiment	1 per Armored Cavalry Regiment	To increase the combat effectiveness of the amored cavalry regiment by accomplishing mobility, countermobility, survivability, and limited sustainment engineering tasks. To provide an engineer special staff section for the regiment. To perform infantry combat missions when required.
Engineer Company, Heavy Separate Brigade	Organic to Heavy Separate Brigade	1 per Heavy Separate Brigade	To increase the combat effectiveness of the heavy separate brigade by accomplishing mobility, countermobility, and survivability tasks. To provide an engineer special staff section for the brigade. To perform infantry combat missions when required.
Engineer Company, Separate Airborne Brigade	Organic to Separate Airborne Brigade	1 per Separate Airborne Brigade	To increase the combat effectiveness of the separate airborne brigade by accomplishing mobility, countermobility, survivability, and sustainment engineering tasks. To provide an engineer special staff section for the brigade. To perform infantry combat missions when required.

Engineer Unit	Normal Assignment	Normal Basis of Allocation	Organizational Mission Statement
Engineer Company, Light Equipment (Airborne/Light)	To corps or other major tactical command; attached to Engineer Brigade, Group, or Battalion	1 per Light, Air Assault and Airborne Division as required	To augment engineer operational capabilities in support of light force operations with engineer equipment.
Engineer Combat Support Equipment Company	To corps; attached to Engineer Brigade or Group	1 per Engineer Brigade or Group	To support engineer combat operations with construction equipment.
Engineer Medium Girder Bridge Company	To corps; attached to Engr Bde or Gp	4 per corps	To provide personnel and equipment to transport, assemble, disassemble, and maintain medium girder bridge equipment. To provide dump trucks for earth moving and engineer mission cargo hauling in emergencies by immobilizing bridge loads.
Engineer Panel Bridge Company	To corps; attached to Engineer Brigade or Group	2 per corps	To provide personnel and equipment to load, transport, maintain, and advise on the erection of panel bridge equipment. To provide dump trucks for earth moving, and engineer mission cargo hauling in emergencies by immobilizing bridge loads.
Engineer Float Bridge Company	To corps; attached to Engineer Brigade or Group	2 per corps	To provide personnel and equipment to load, transport, maintain, and supervise erection of tactical stream crossing equipment. To provide trucks for engineer mission cargo hauling in emergencies by immobilizing bridge loads.
Engineer Assault Float Bridge Company	To corps; attached to Engineer Brigade or Group	4 per corps	To provide personnel and equipment to transport, assemble, disassemble, and maintain the ribbon bridge. To provide trucks for engineer mission cargo hauling of palletized cargo in emergencies.

Engineer Unit	Normal Assignment	Normal Basis of Allocation	Organizational Mission Statement
Engineer Construction Support Company	To an ENCOM; attached to Engineer Brigade or Group	1 per Engineer Brigade or Group	To provide rock crushing, bituminous mixing, paving and other construction support equipment with operators. To increase the capabilities of the construction group in major horizontal construction projects, such as highways, storage facilities, and airfields.
Engineer Dump Truck Company	To TA; attached to Engineer Brigade or Group	1 per Engineer Brigade or Group	To operate dump trucks for movement of bulk materials in support in support of other engineer units.
Engineer Port Construction Company	To an ENCOM; attached to Engineer Brigade or Group	1 per major port	To provide specialized engineer support in developing, rehabilitating, and maintaining port facilities to include LOTS operations.
Engineer Pipeline Construction Company	To an ENCOM; attached to Engineer Brigade or Group	1 per Engineer Brigade or Group engaged in pipeline construction	To provide personnel and specialized equipment to assist engineer units in construction, rehabilitation. and maintenance (except organizational) of pipeline systems. To provide a limited independent capability for construction, rehabilitation, and maintenance of pipeline systems. To assist using units in specialized repairs.

Section IV
Separate Engineer Teams

Engineer Topographic Teams	Dependent upon the team	As required	To provide engineer topographic and intelligence teams for specialized support to the Army.

Engineer Unit	Normal Assignment	Normal Basis of Allocation	Organizational Mission Statement
Engineer Firefighting Teams	As required; can be formed into platoons	As required; 3 Plts per ASG	To provide firefighting service support to the TO.
Engineer Equipment Operating Teams	Attached to Engineer Combat Battalion (Heavy) fixed-size unit, or composite unit	As required dependent on type of team	To provide engineer equipment operating teams to the Army.
Engineer Construction, Utilities, and Electrical Power Teams	Attached to fixed-size unit or composite unit	As required	To provide construction, utilities, and electrical power teams for specialized engineer support in a TO.
Dredging Teams	As required	As required	To provide teams for the operation of engineer dredges.
Engineer Civic Action Teams	Attached to fixed-size unit or composite unit	As required	To provide specialized engineer support for civil action operations.
Engineer Bridge Team	Attached to engineer units	As required	To provide light stream crossing equipment and technical advice on its erection and operation for the assault phase of a tactical river crossing and for other water-borne operations.

APPENDIX B. ACRONYMS

This appendix provides a glossary of acronyms which are used throughout this thesis.

ACRONYM	SUMMARY OF ACRONYM
A	Attrition Fraction
ABN	Airborne
ACE	Armored Combat Earthmover
AD	Air Defense
APC	Armored Personnel Carrier
ASG	Area Support Group
ATC	Arc Total Cost
ATCAL	Attrition Calibration Model
AVLB	Armored Vehicle Launched Bridge
BADD	Blue Attack, Red conducts Deliberate Defense
BADH	Blue Attack, Red conducts Hasty Defense
BADI	Blue Attack, Red conducts Intense Defense
BCD	Bridge Crossing Delay
BD	Bypass Delay
Bde	Brigade
BED	Bridge Erection Delay
BL	Breaching Loss
Bn	Battalion
BOS	Battlefield Operating System
BT	Breach Time
BTL	Bull-Through Loss
C3I	Command, Control, Communications, and Intelligence
CBT HVY	Combat Heavy
CCS	Constant Crossing Speed
CEM	Concepts Evaluation Model
CEV	Combat Engineer Vehicle
CL	Crossing Loss
Co	Company
COMMZ	Communications Zone
COSAGE	Combat Sample Generator
CTF	Contingency Task Force
CUS	Current Unit Strength
D	Delay Fraction
DD	Discovery Delay
DIV	Division
DL	Discovery Loss
DMZ	Demilitarized Zone
DPL	Decision Programming Language
EFAM	Engineer Functional Area Models

ACRONYM	SUMMARY OF ACRONYM
EMIP	Engineer Model Improvement Program
EN	Engineer
ENCOM	Engineer Command
FBD	Fraction of Speed for Breach/Reconnaissance Delay
FCD	Fraction of Speed for Crossing Delay
FLD	Front Line Depth
FLOT	Forward Line of Troops
FM	Field Manual
FTLM	Future Theater Level Model
Gp	Group
GW	Gap Width
HHC	Headquarters and Headquarters Company
HITL	Human-In-The-Loop
HQ	Headquarters
HR	Hour
ID	Infantry Division
IPB	Intelligence Preparation of the Battlefield
J-8	Force Structure, Resource and Assessment Directorate of the Joint Staff
J-STOCHWAR	Joint Stochastic Warfare Analysis Research
JTF	Joint Task Force
JTLS	Joint Theater Level Simulation Model
JWAEP	Joint Warfare Analysis Experimental Prototype Model
LBS	Pounds
LOTS	Logistics Over the Shore
MECH	Mechanized
METT-T	Mission, Enemy, Troops Available, Terrain, and Time
MFD	Minefield Density
MGB	Medium Girder Bridge
MICLIC	Mine Clearing Line Charge
MLC	Military Load Class
MMO	Maneuver Mobility
MOE	Measure of Effectiveness
MORS	Military Operations Research Society
MSR	Main Supply Route
NBC	Nuclear, Biological, and Chemical
OCOKA	Observation, Cover and Concealment, Obstacles, Key Terrain, and Avenues of Approach
OD	Obstacle Depth
OF	Obstacle Frontage
OPCON	Operational Control
OSR	Obstacle Strength Reduction

ACRONYM	SUMMARY OF ACRONYM
P(OBS EXIST)	Probability of Obstacle Existence
Plt	Platoon
QTY	Quantity
R	Radius of Unit
RADD	Red Attack, Blue conducts deliberate Defense
RADH	Red Attack, Blue conducts Hasty Defense
RADI	Red Attack, Blue conducts Intense Defense
S	Unopposed Speed of Unit
SEE	Small Equipment Excavator
SIMTAX	Simulation Taxonomy
STD DEV	Standard Deviation
STONS	Short Tons
TA	Theater Army
TACWAR	Tactical warfare Model
TD	Total Delay
TGT	Target
TL	Total Losses
TO	Theater of Operations
TO&E	Table of Organization and Equipment
TOPO	Topographic
TP	Time Penalty
UD	Unit Depth
UFW	Unit Frontage Width
US	United States
USA	United States Army
USAF	United States Air Force
VEH	Vehicles
VIC	Vector-In-Commander
W_i	Weighting Factor

APPENDIX C. ENGINEER STRUCTURES

This appendix provides the necessary information on the mobility engineer units so that a JWAEP user can properly input the required parameters.

1. **UNIT**: Divisional Engineer Battalion (3 in each mechanized or armored division)
   SIDE: 1
   CLASS: 1002
   FUNCTION: 2
   MAX SUPPORT RANGE: 30
   GROUP: 1008
   AD TYPE: 0

EQUIPMENT	QUANTITY	BREACH RATE	GAP WIDTH SPAN
Combat Engineer Vehicle (CEV)	12	5000	0
Armored Personnel Carrier	28	0	0
AVLB	12	0	17
MICLIC	12	1500	0
ACE	21	200	0

WEAPONS	BASIS OF ISSUE	FORCE KILLING WEAPON (YES/NO)
165 MM Demo Gun	1 per CEV	No
7.62 MM Machine Gun	1 per CEV	Yes
50 Cal Machine Gun	1 per CEV	Yes
Mine Clearing Rake	1 per CEV	No
Debris Blade	1 per CEV	No
MICLIC	12 per Engr Bn	No
7.62 MM Machine Gun	1 per ACE	Yes
Excavation Blade	1 per ACE	No

2. **UNIT**: Corps Mechanized Combat Engineer Battalion
   SIDE: 1
   CLASS: 1002
   FUNCTION: 2
   MAX SUPPORT RANGE: 30
   GROUP: 1008
   AD TYPE: 0

EQUIPMENT	QUANTITY	BREACH RATE	GAP WIDTH SPAN
Combat Engineer Vehicle	12	5000	0
AVLB	12	0	17
MICLIC	12	1500	0
ACE	18	200	0
Armored Personnel Carrier	28	0	0
SEE	6	100	0

WEAPONS	BASIS OF ISSUE	FORCE KILLING WEAPON (YES/NO)
165 MM Demo Gun	1 per CEV	No
7.62 MM Machine Gun	1 per CEV	Yes
50 Cal Machine Gun	1 per CEV	Yes
Mine Clearing Rake	1 per CEV	No
Debris Blade	1 per CEV	No
MICLIC	12 per Engr Bn	No
7.62 MM Machine Gun	1 per ACE	Yes
Excavation Blade	1 per ACE	No

3. **UNIT**: Corps Combat Engineer Battalion (Light)
   SIDE: 1
   CLASS: 1002
   FUNCTION: 2
   MAX SUPPORT RANGE: 30
   GROUP: 1008
   AD TYPE: 0

EQUIPMENT	QUANTITY	BREACH RATE	GAP WIDTH SPAN
SEE	6	100	0

4. **UNIT**: Corps Combat Engineer Battalion (Airborne)
   SIDE: 1
   CLASS: 1002
   FUNCTION: 2
   MAX SUPPORT RANGE: 30
   GROUP: 1008
   AD TYPE: 0

EQUIPMENT	QUANTITY	BREACH RATE	GAP WIDTH SPAN
Scoop Loader	9	100	0
D5 Dozer	15	200	0
SEE	18	100	0
MICLIC	6	1500	0

5. **UNIT**: Medium Girder Bridge (MGB) Company
   SIDE: 1
   CLASS: 1002
   FUNCTION: 2
   MAX SUPPORT RANGE: 30
   GROUP: 1008
   AD TYPE: 0

EQUIPMENT	QUANTITY	BREACH RATE	GAP WIDTH SPAN
Medium Girder Bridge Set	4 Sets/Company	0	102 FPS (MLC 60)

6. **UNIT:** Corps Engineer Ribbon Bridge Company
SIDE: 1
CLASS: 1002
FUNCTION: 2
MAX SUPPORT RANGE: 30
GROUP: 1008
AD TYPE: 0

EQUIPMENT	QUANTITY	BREACH RATE	GAP WIDTH SPAN
Corps Ribbon Bridge	30 interior bays 12 ramp bays	0	215 meters

APPENDIX D. CLOSE COMBAT DECISION ANALYSIS FRAMEWORK

This appendix provides the decision analysis framework for modeling the engineer mobility tactic employment in a close combat environment in JWAEP. This framework explicitly considers the numerous uncertainties involved in this decision compared to current representation of this engineer tactic employment in close combat using ATCAL and COSAGE runs.

Decision analysis techniques are commonly used in making decisions which involve complexity, numerous inherent uncertainties, multiple objectives, and varying perceptions. These techniques enable the commander to better perceive and deal with uncertainty in the absence of doctrine and specified guidance under intense battle conditions.

Influence diagrams and decision trees are effective decision analysis tools to handle complex decisions which characteristically contain uncertainty, and multiple objectives [9:3]. The utilization of these tools can help define and understand the interrelationship of factors in order to model the tactical mobility breaching decisions in a close combat environment.

An influence diagram is a decision analysis tool used to depict and solve a decision problem. The influence diagram provides a simple graphical representation of a decision. Its design captures the major factors that bear upon a problem without overburdening the decision maker with inordinate amounts of detail. Clemen describes the construction of influence diagrams for decisions involving uncertainties. He uses ellipses for chance events, rectangles for decision nodes, and octagons for decision outcomes or value nodes. Arrows represent relevance of events to one another [9:34]. The influence diagram in

Figure D-1 shows the basic elements that impact the modeling of tactical mobility breaching decisions.

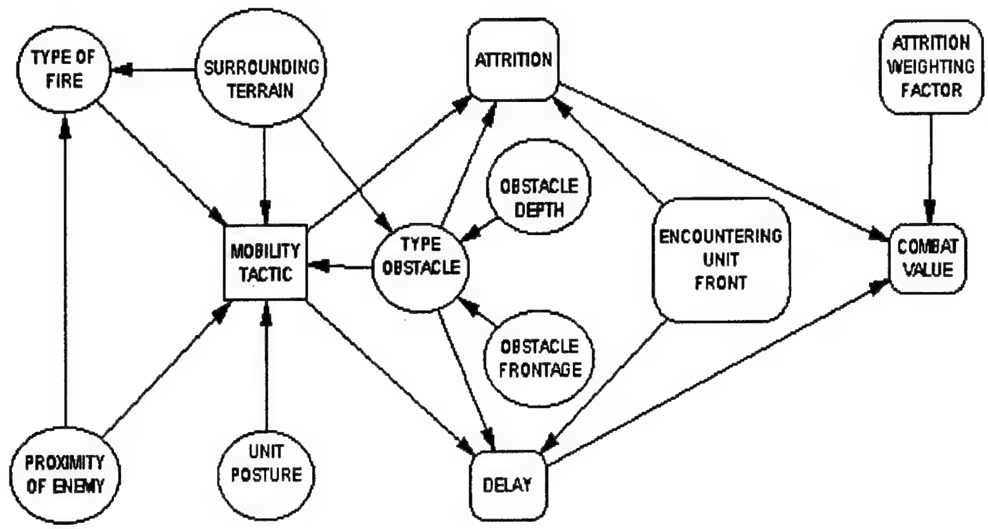

Figure D-1 Influence Diagram: Modeling Tactical Mobility Breaching Tactics

The outcome achieved from this diagram will be the employment decision for the best tactical mobility breaching tactic in a close combat environment. Thus, the influence diagram is a concise display of the factors that are relevant to model mobility breaching tactics. Decision makers can quickly identify the relationships among the factors in the problem.

The decision tree is another decision analysis tool that will be useful in modeling mobility breaching tactics. Clemen states that decision trees show more surface detail than an influence diagram and are more beneficial to represent the minutia of decision problems. Similar to influence diagrams, circles and squares represent stochastic events and decisions, respectively [9:49]. Figure D-2 depicts a portion of the influence diagram as a short hand decision tree.

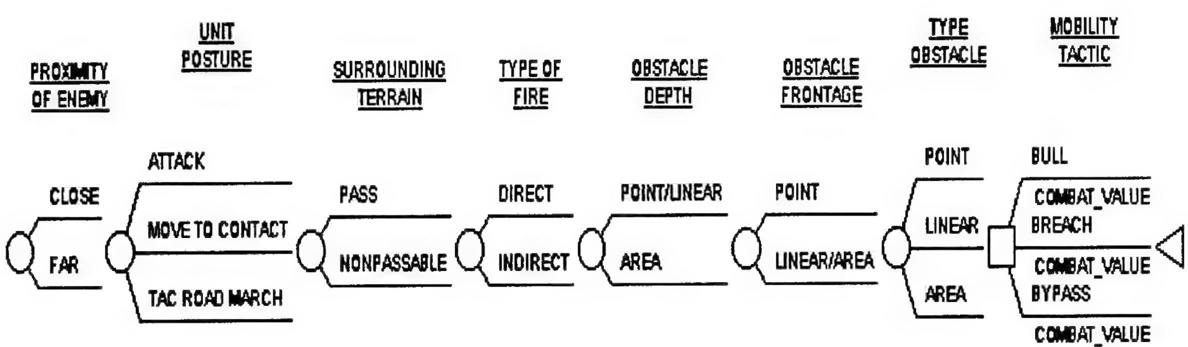

Figure D-2 Decision Tree: Modeling Tactical Mobility Breaching Tactics

Decision trees can effectively model uncertainties such as potential delay and attrition. However, asymmetric decision trees reflecting all possible outcomes tend to get very cumbersome and unmanageable for more complex problems [9:55]. Figure D-2 simply illustrates a short hand symmetric decision tree for clarity purposes.

Both influence diagrams and decision trees are complementary techniques and each provide insight into decision problems. The influence diagram omits specific details, but it focuses on the problem in a more aggregate, manageable fashion that may still capture the critical aspects of the problem. The decision tree shows more detail and specificity, but it becomes unmanageable as problem complexity increases. For these reasons and due to the size of the problem, the modeler should consider the use of influence diagrams with embedded decision trees. There are many decision analysis solvers; this analysis used the Decision Programming Language (DPL™) Version 3.1.

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VITA

Captain Brian K. Hobson was born on 21 January 1963 at Fort Benning, Georgia. Upon graduation from Perry High School in Canton, Ohio in 1981, he entered the United States Military Academy at West Point. Upon graduation from the Academy in 1985, he was commissioned as a Second Lieutenant in the Corps of Engineers.

After graduation from the Engineer Officer Basic Course at Fort Belvoir, Virginia, CPT Hobson served as a Platoon Leader and Company Executive Officer in the 44th Engineer Battalion stationed in Korea. Upon tour completion, he was assigned to the 20th Engineer Brigade (Combat)(Airborne) at Fort Bragg, North Carolina. Here, he served as a Company Executive Officer, Brigade Supply Officer and Training Officer, Battalion Adjutant and Company Commander. Following this assignment and the Engineer Officer Advanced Course at Fort Leonard Wood, Missouri, he became the Operations Officer in the I Corps Engineer Section at Fort Lewis, Washington. In his next duty, CPT Hobson served as a Battalion Operations Officer, Company Commander, and Group Plans Officer for the 555th Combat Engineer Group at Fort Lewis.

Captain Hobson entered the Air Force Institute of Technology (AFIT), Wright-Patterson Air Force Base, Ohio in 1994. After graduating in March 1996 with a Master of Science degree in Operations Research, he was assigned to the Ph.D. program at AFIT. Captain Hobson is married to the former Karen Harvey and has six children: sons Rafael, Manolo, and Nick, and daughters Katie, Abby, and Tiffany.

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13. ABSTRACT *(Maximum 200 words)*

This thesis describes the development of a methodology to model theater-level mobility engineering assets in the Joint Staff's Joint Warfare Analysis Experimental Prototype(JWAEP) and to quantify the Army doctrine that guides the task organization of engineers for combat and quantifies engineer mobility effects in combat. The methodology incorporates theater-level mobility engineering assets into the JWAEP by using METT-T principles which reflect Army doctrine, and combines them with the existing basic concepts in other theater-level models. Additional aspects include determining the manmade and natural obstacle delay and attrition effects, determining the obstacle intelligence acquisition procedures, updating the total cost of the Dykstra algorithm to reflect obstacle effects, identifying solution techniques, verifying the results, and making recommendations.

The proposed solution techniques provide a feasible methodology for maximizing the utility of organizing mobility engineers for combat based on a perception of existing obstacles and potential obstacle delay and attrition effects. The algorithms incorporate the engineer estimate process for organizing engineers for combat and employ appropriate engineer doctrine.

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